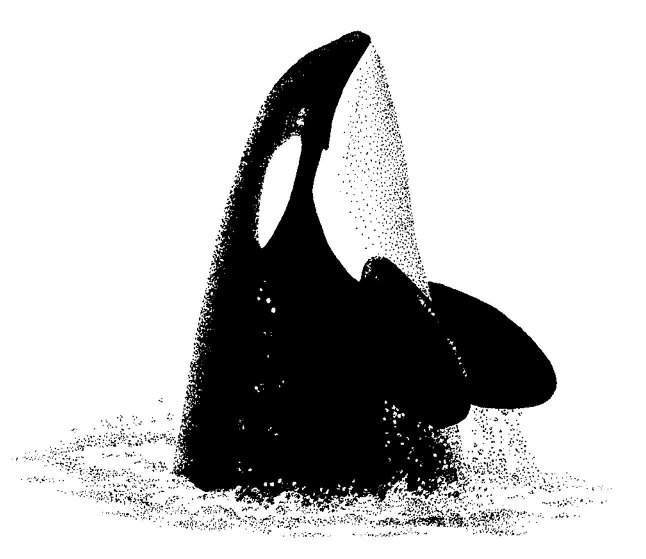
Preliminary Draft

Conservation Plan for

Southern Resident Killer Whales (*Orcinus orca*)

Prepared by
National Marine Fisheries Service



March 2005

Introduction to the Preliminary Draft Conservation Plan

Southern resident killer whales are currently designated as a "depleted stock" under the Marine Mammal Protection Act (MMPA), which requires the development of a Conservation Plan. The population has also been proposed for listing as "threatened" under the U.S. Endangered Species Act (ESA). At the time of a final ESA listing determination, a Recovery Plan would be developed. Fortunately, the requirements for Conservation and Recovery Plans are virtually identical. The MMPA requires the agency to model Conservation Plans after Recovery Plans under section 4(f) of the ESA.

The National Marine Fisheries Service (NMFS) held a series of workshops in 2003-2004 to receive input from a variety of stakeholders on ideas for management actions to include in this plan. To continue with our efforts in maintaining a transparent process, we are providing this preliminary draft document for review. The preliminary draft is incomplete at this time and we are hoping that stakeholders can assist us with filling in several gaps.

1. We would like the plan to reflect current and ongoing efforts that may already be contributing to the conservation of the southern residents. Although some programs are mentioned that we are aware of, there are likely many others being conducted by government agencies, advocacy groups, and industry that can be viewed in light of killer whale conservation and should be noted in the plan. Please provide information on specific programs that could be named under a management activity listed in the narrative outline of conservation actions.

2. The MMPA requires that "estimates of the time required and the cost to carry out the measures needed to achieve the plan's goal" be included in the plan, which is usually accomplished in an implementation schedule. We have begun developing a schedule with management actions, time frames, and costs, but are only in the initial stages of identifying the costs for some actions. We will need assistance in evaluating costs and time lines for proposed management activities, as well as programs that are already ongoing and funded, to complete the implementation schedule.

3. At this time, the initial draft does not include criteria describing the conditions when the depleted designation could be removed. We have included a placeholder in the preliminary plan for developing MMPA criteria and we have drafted a list of questions that will be considered in developing criteria. We are actively gathering relevant information and welcome additional input to assist in establishing objective measurable criteria to include in the plan. We will continue to develop criteria for inclusion in the next draft of the plan.

An overview of the Preliminary Draft Conservation Plan was presented at two public meetings held:

February 17th, Seattle Aquarium, Seattle, WA
February 28th, Friday Harbor Labs, San Juan Island, WA

Written comments on the Preliminary Draft Conservation Plan will be accepted through May 15, 2005. Comments can be submitted via e-mail to orca.plan@noaa.gov or by mail to:

Lynne Barre
NMFS, Protected Resources Division
7600 Sand Point Way NE
Seattle, WA 98115
U.S.A.

There will be additional opportunities to review and provide comments on the plan. Input received on the preliminary draft will be incorporated into a second draft that will be made available for formal review before the plan is finalized.

I. BACKGROUND

TAXONOMY

Killer whales are members of the family Delphinidae, which includes 17-19 genera of marine dolphins (Rice 1998, LeDuc et al. 1999). Systematic classifications based on morphology have variously placed the genus *Orcinus* in the subfamilies Globicephalinae or Orcininae with other genera such as *Feresa*, *Globicephala*, *Orcaella*, *Peponocephala*, and *Pseudorca* (Slijper 1936, Fraser and Purves 1960, Kasuya 1973, Mead 1975, Perrin 1989, Fordyce and Barnes 1994). However, molecular work suggests that *Orcinus* is most closely related to the Irawaddy dolphin (*Orcaella brevirostris*), with both forming the subfamily Orcininae (LeDuc et al. 1999).

Orcinus has traditionally been considered monotypic, despite some variation in color patterns, morphology, and ecology across its distribution. No subspecies are currently recognized. In the early 1980s, Soviet scientists proposed two new species (*O. nanus* and *O. glacialis*) in Antarctica, based on their smaller sizes and other traits (Mikhalev et al. 1981, Berzin and Vladimirov 1983, Pitman and Ensor 2003). Similarly, Baird (1994, 2002) argued that resident and transient forms in the northeastern Pacific should be treated as separate species due to differences in behavior, ecology, and vocalizations. However, these proposals did not receive wide acceptance (Hoelzel et al. 1998, Rice 1998, Barrett-Lennard 2000). Additional investigation documented genetic distinctions among populations in the northeastern Pacific, but these were considered insufficient to warrant designation of discrete taxa (Hoelzel and Dover 1991, Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001). Hoelzel et al. (2002) reported low diversity and inconsistent geographic patterns in mitochondrial DNA (mtDNA) among worldwide populations, which supported the lack of taxonomic differentiation within the species. Despite these findings, a number of authorities believed that the classification of killer whales as a single species without subspecies was inaccurate (Krahn et al. 2002), as suggested by the recent recognition of three distinct forms in Antarctica (Pitman and Ensor 2003). Preliminary evidence suggests that multiple ecotypes may also occur in Norway and New Zealand (Waples and Clapham 2004). Furthermore, the low genetic diversity of killer whales may be more reflective of their matrilineal social structure (Whitehead 1998) than an absence of taxonomic separation.

Ongoing genetic studies are providing further understanding of the relationships among killer whale populations (Waples and Clapham 2004). However, many of the results are open to multiple interpretations, thus precluding firm taxonomic conclusions from being made. Analyses of mitochondrial DNA diversity reveal greater genetic variation in the species than previously recognized, based on the discovery of a much larger number of haplotypes. Two major groups of haplotypes exist (LeDuc and Taylor 2004), as illustrated in a preliminary phylogenetic tree prepared by R. LeDuc (Krahn et al. 2004a). The largest clade appears to be distributed worldwide and includes resident and offshore whales from the northeastern Pacific, other fish-eating populations, and some mammal-eating populations from the eastern tropical Pacific, Argentina, and the Gulf of Mexico. The second clade is known thus far only from the North Pacific and Antarctica, and includes the mammal-feeding transient whales from the west coast of North America. Hoelzel (2004), using mitochondrial DNA sequence data, similarly found that transient haplotypes were divergent from those of other populations in the North Pacific and Iceland. Total genetic variation in Antarctic killer whales is comparable to that in combined populations from the rest of the world (LeDuc and Pitman 2004). Based on mitochondrial DNA, Hoelzel et al. (2002) postulated that killer whales as a species experienced a population bottleneck perhaps 145,000 to 210,000 years ago.

This information, together with tentative morphological evidence (C. W. Fung and L. G. Barrett-Lennard, unpubl. data), has caused most cetacean taxonomists to now believe that multiple species or subspecies of killer whales exist worldwide (Krahn et al. 2004a, Reeves et al. 2004, Waples and Clapham 2004). Most participants at a taxonomy workshop held in April-May 2004 concluded that sufficient information currently exists to formally recognize resident and transient whales in the northeastern Pacific and two or three forms from Antarctica as subspecies, with further study needed to determine whether classification as full species is appropriate (Reeves et al. 2004). If subspecies designations proceed, a lengthy review of museum material and published species descriptions is necessary before assignment of nomenclature can occur (Krahn et al. 2004a, Perrin 2004). Based on this evidence, Krahn et al. (2004a) concluded that all North Pacific resident killer whales should be treated as a single unnamed subspecies distinct from offshore and transient whales.

Common Names

The name “killer whale” originates from early whalers and is appropriately based on the species’ predatory habits, as well as its large size, which distinguishes it from other dolphins. Other common names currently or formerly used in North America include “orca,” “blackfish,” “killer,” “grampus,” and “swordfish.” The name “orca” has become increasingly popular in recent decades as a less sinister alternative to “killer whale” (Spalding 1998). A variety of Native American names also exist, including *klasqo’kapix* (Makah, Olympic Peninsula), *ka-kow-wud* (Quileute, Olympic Peninsula), *max’inux* (Kwakiutl, northern Vancouver Island), *qaqawun* (Nootka, western Vancouver Island), and *ska-ana* (Haida, Queen Charlotte Islands) (Hoyt 1990, Matkin et al. 1999a, Ford et al. 2000).

DESCRIPTION

Killer whales are the world’s largest dolphin. The sexes show considerable size dimorphism, with males attaining maximum lengths and weights of 9.0 m and 5,568 kg, respectively, compared to 7.7 m and 3,810 kg for females (Dahlheim and Heyning 1999). Adult males develop larger pectoral flippers, dorsal fins, tail flukes, and girths than females (Clark and Odell 1999). The dorsal fin reaches heights of 1.8 m and is pointed in males, but grows to only 0.7 m and is more curved in females (Figure 1). Killer whales have large paddle-shaped pectoral fins and broad rounded heads with only the hint of a facial beak. The flukes have pointed tips and form a notch at their midpoint on the trailing edge. Ten to 14 teeth occur on each side of both jaws and measure up to 13 cm in length (Eschricht 1866, Scammon 1874, Nishiwaki 1972). Skull morphology and other anatomical features are described by Tomilin (1957) and Dahlheim and Heyning (1999).

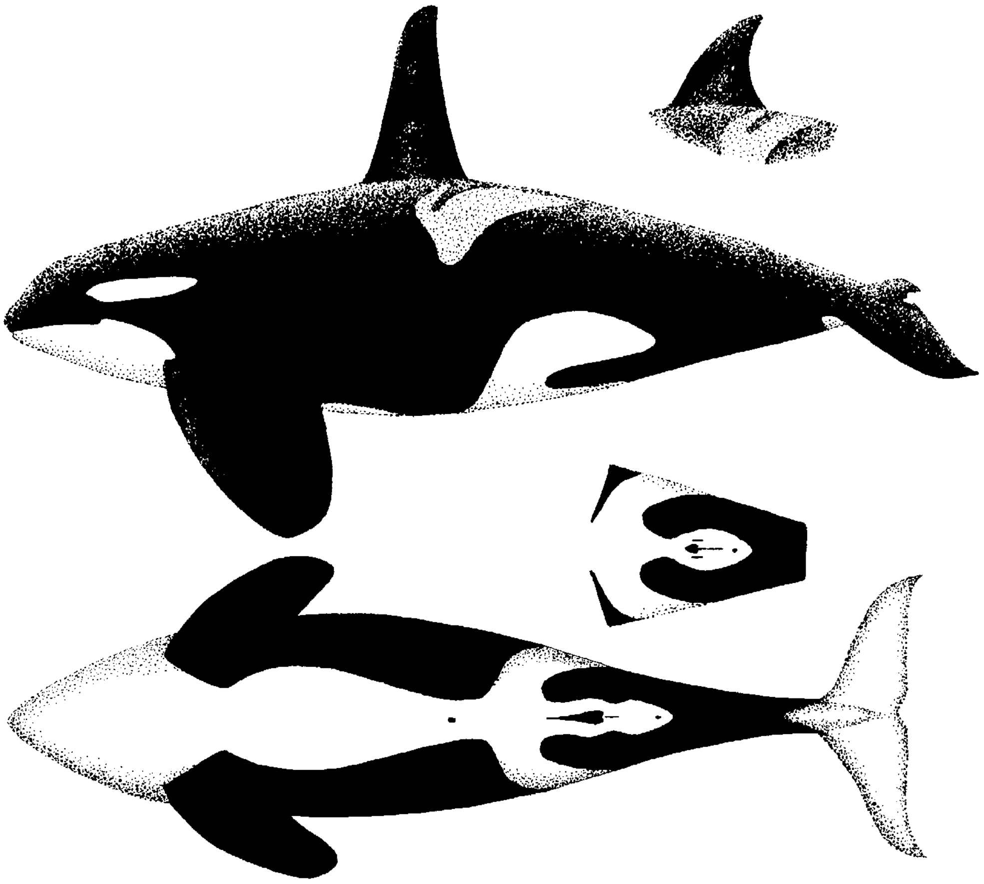


Figure 1. Lateral and ventral views of an adult male killer whale. Small insets show the dorsal fin and genital pigmentation of a female. Adapted from Dahlheim and Heyning (1999) and Ford et al. (2000).

Killer whales are easily identifiable by their distinctive black-and-white color pattern, which is among the most striking of all cetaceans. Animals are black dorsally and have a white ventral region extending from the chin and lower face to the belly and anal region (Figure 1). The underside of the tail fluke is white or pale gray, and may be thinly edged in black. Several additional white or gray markings occur on the flanks and back. These include a small white oval patch behind and above the eye, a larger area of white connected to the main belly marking and sweeping upward onto the lower rear flank, and a gray or white "saddle" patch usually present behind the dorsal fin. These color patterns exhibit regional and age variation (Carl 1946, Evans et al. 1982, Baird and Stacey 1988, Ford et al. 2000, Pitman and Ensor 2003). Infants feature yellowish, rather than white, markings. Each whale has a uniquely shaped and scarred dorsal fin and saddle patch, which permits animals to be recognized on an individual basis, as depicted in photo-identification catalogs, such as those compiled for the northeastern Pacific region (e.g., Black et al. 1997, Dahlheim 1997, Dahlheim et al. 1997, van Ginneken et al. 1998, 2000, Matkin et al. 1999a, Ford and Ellis 1999, Ford et al. 2000). Shape and coloration of the saddle often differs on the left and right sides of an animal (Ford et al. 2000, van Ginneken et al. 2000). Eye-patch shape is also unique among individuals (Carl 1946, Visser and Mäkeläinen 2000). In the Antarctic, several populations of killer whales display grayish dorsal "capes" extending over large portions of the back and flanks (Evans et al. 1982, Visser 1999a, Pitman and Ensor 2003).

In addition to the characters mentioned above, male and female killer whales are distinguishable by pigmentation differences in the genital area (Figure 1; Ford et al. 2000). Females have a roughly circular or oval white patch surrounding the genital area. Within this patch, the two mammary slits are marked with gray or black and are located on either side of the genital slit, which also usually has a dark marking. Males have a more elongated white patch surrounding the genital area, a larger darker spot at the genital slit, and lack the darkly shaded mammary slits.

When viewed at long distances, false killer whales (*Pseudorca crassidens*) and Risso's dolphins (*Grampus griseus*) can be mistaken for female and immature killer whales (Leatherwood et al. 1988). Blows of killer whales are low and bushy-shaped, reaching a height of about 1-3 m (Scammon 1874, Scheffer and Slipp 1948, Eder 2001). Scheffer and Slipp (1948) described the sound of blowing as "a quick breathy puff, louder and sharper and lacking the double gasp of the harbor porpoise" (*Phocoena phocoena*).

DISTRIBUTION

Killer whales have a cosmopolitan distribution considered the largest of any cetacean (Figure 2). The species occurs in all oceans, but is generally most common in coastal waters and at higher latitudes, with fewer sightings from tropical regions (Dahlheim and Heyning 1999; Forney and Wade, in press). In the North Pacific, killer whales occur in waters off Alaska, including the Aleutian Islands and Bering Sea (Murie 1959, Braham and Dahlheim 1982, Dahlheim 1994, Matkin and Saulitis 1994, Miyashita et al. 1995, Dahlheim 1997, Waite et al. 2002), and range southward along the North American coast and continental slope (Norris and Prescott 1961, Fiscus and Niggol 1965, Gilmore 1976, Dahlheim et al. 1982, Black et al. 1997, Guerrero-Ruiz et al. 1998). Populations are also present along the northeastern coast of Asia from eastern Russia to southern China (Zenkovich 1938, Tomilin 1957, Nishiwaki and Handa 1958, Kasuya 1971, Wang 1985, Miyashita et al. 1995). Northward occurrence in this region extends into the Chukchi and Beaufort Seas (Ivashin and Votrogov 1981, Lowry et al. 1987, Matkin and Saulitis 1994). Sightings are generally infrequent to rare across the tropical Pacific, extending from Central and South America (Dahlheim et al. 1982, Wade and Gerrodette 1993) westward to much of the Indo-Pacific region (Tomich 1986, Eldredge 1991, Miyashita et al. 1995, Reeves et al. 1999, Mobley et al. 2001, Visser and Bonoccorso 2003; Forney and Wade, in press). Killer whales occur broadly in the world's other oceans, with the exception of the Arctic Ocean (Figure 2; Miyashita et al. 1995, Dahlheim and Heyning 1999; Forney and Wade, in press).

Figure 2. Worldwide range of killer whales. Hatched areas depict the distribution of known records. White areas are probably also inhabited, but documented sightings are lacking. Adapted from Miyashita et al. (1995) and Dahlheim and Heyning (1999), with additional information from Reeves and Mitchell (1988b), Wade and Gerrodette (1993), Andersen and Kinze (1999), and Reeves et al. (1999).

CLASSIFICATION OF KILLER WHALES IN THE NORTHEASTERN PACIFIC

Three distinct forms of killer whales, termed as residents, transients, and offshores, are recognized in the northeastern Pacific Ocean. Although there is considerable overlap in their ranges, these populations display significant genetic differences due to a lack of interchange of member animals (Stevens et al. 1989, Hoelzel and Dover 1991, Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001, Hoelzel 2004, Krahn et al. 2004a). Important differences in ecology, behavior, morphology, and acoustics also exist (Baird 2000, Ford et al. 2000). The names “resident” and “transient” were coined during early studies of killer whale communities in the northeastern Pacific (Bigg 1982), but continued research has shown that neither term is particularly descriptive of actual movement patterns (Dahlheim and Heyning 1999, Baird and Whitehead 2000, Baird 2001). Both names, plus “offshore,” are currently applied only to killer whales occurring in this region, but may also be appropriate for some populations off eastern Asia (Krahn et al. 2002). Similar differences among overlapping populations of killer whales have been found in Antarctica (Berzin and Vladimirov 1983, Pitman and Ensor 2003) and may eventually be recognized in the populations of many localities (Hoelzel and Dover 1991, Ford et al. 1998).

Resident Killer Whales

Resident killer whales are distributed from Alaska to California, with four distinct communities recognized: southern, northern, southern Alaska, and western Alaska (Krahn et al. 2002, 2004a). Resident animals differ from transient and offshore killer whales by having a dorsal fin that is more curved and rounded at the tip (Ford et al. 2000). Residents exhibit five patterns of saddle patch pigmentation, two of which are shared with transients (Baird and Stacey 1988). Residents also differ in vocalization patterns and skull traits, feed primarily on fish, and occur in large stable pods typically comprised of 10 to about 60 individuals (Ford 1989, Felleman et al. 1991, Ford et al. 1998, 2000, Saulitis et al. 2000; C. W. Fung and L. G. Barrett-Lennard, unpubl. data). An additional resident community, known as the western North Pacific residents, occurs off eastern Russia and perhaps Japan (Hoelzel 2004, Krahn et al. 2004a).

Southern residents. This population consists of three pods, identified as J, K, and L pods, that reside for part of the year in the inland waterways of the Strait of Georgia, Strait of Juan de Fuca, and Puget Sound in Washington and British Columbia, especially during the spring, summer, and fall (Ford et al. 2000, Krahn et al. 2002). Pods regularly visit coastal sites off Washington and Vancouver Island (Ford et al. 2000), and are known to travel as far south as central California and as far north as the Queen Charlotte Islands (Figure 3). Winter movements and distribution are poorly understood for the population. Although there is considerable overlap in the geographic ranges of southern and northern residents, pods from the two populations have not been observed to intermix (Ford et al. 2000). Genetic analyses using nuclear (microsatellite) and mitochondrial DNA further indicate that the two populations are reproductively isolated (Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001).

Northern residents. This community contains 16 pods (A1, A4, A5, B1, C1, D1, H1, I1, I2, I18, G1, G12, I11, I31, R1, and W1) that reside primarily from central Vancouver Island (including the northern Strait of Georgia) to Frederick Sound in southeastern Alaska (Figure 3; Dahlheim et al. 1997, Ford et al. 2000), although animals occasionally venture as far south as the Strait of Juan de Fuca, San Juan Islands, and the western Olympic Peninsula (Barrett-Lennard and Ellis 2001, Calambokidis et al. 2004, Wiles 2004; J. K. B. Ford, unpubl. data). From June to October, many northern resident pods congregate in the vicinity of Johnstone Strait and Queen Charlotte Strait off northeastern Vancouver Island, but movements and distribution during other times of the year are much less well known (Ford et al. 2000). In southeastern Alaska, northern residents have been seen within 500 m of pods from the southern Alaska resident community (Krahn et al. 2004a) and limited gene flow may occur between these two populations (Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001).

Southern Alaska residents. Southern Alaska resident killer whales inhabit the waters of southeastern Alaska and the Gulf of Alaska, including Prince William Sound, Kenai Fjords, and Kodiak Island (see Figure 1 in Krahn et al. 2004a) (Dahlheim et al. 1997, Matkin and Saulitis 1997, Matkin et al. 1997, 1999a). At least 25 pods have been identified (Matkin et al. 2003;

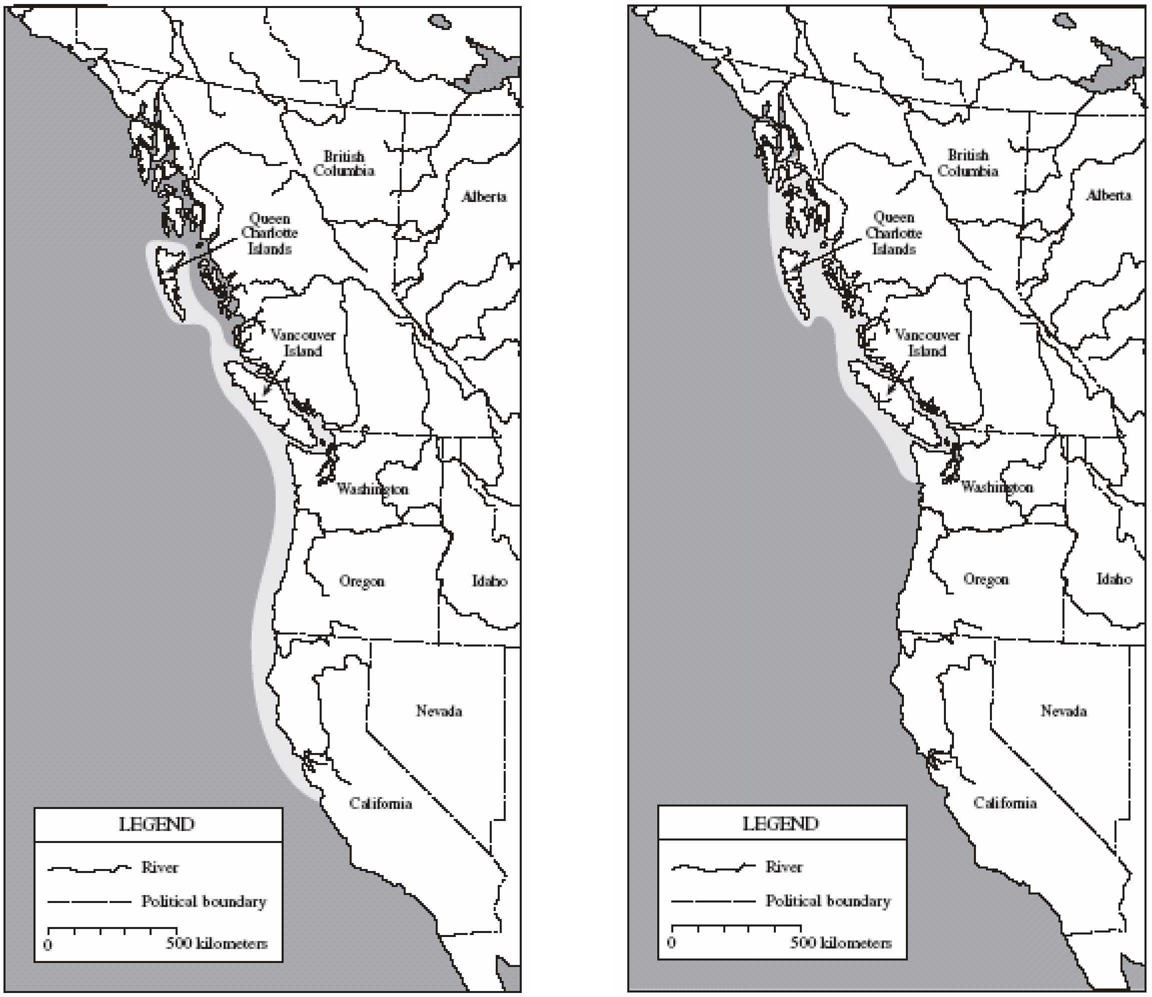


Figure 3. Geographic ranges (light shading) of the southern resident (left) and northern resident (right) killer whale populations in the northeastern Pacific. The western pelagic boundary of the ranges is ill-defined.

Angliss, in prep.). However, some groups remain poorly known and a full inventory of the community has not yet been accomplished (C. O. Matkin, pers. comm.). Genetic analyses indicate that this population is most closely related to the northern residents and that occasional intermatings may occur between the two (Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001). Southern Alaska residents are also closely related to the western Alaska resident community (Hoelzel 2004) and have been observed once off Kodiak Island in association with whales from this population (M. E. Dahlheim, unpubl. data).

Western Alaska residents. The distribution and abundance of this community is less understood, but its range includes coastal and offshore waters west of Kodiak Island to the Aleutian Islands and the Bering Sea (see Figure 1 in Krahn et al. 2004a) (Dahlheim 1997, Krahn et al. 2004a). It is also thought to be the largest resident community in the region (Krahn et al. 2004a). An unknown number of pods is present and pod names have not yet been assigned. Recent genetic studies by Hoelzel (2004) suggest that the population is more closely related to the southern Alaska residents than to the western North Pacific residents.

Transient Killer Whales

Transients do not associate with resident and offshore whales despite having a geographic range that is largely sympatric with both forms (Figure 4). Compared to residents, transients occur in smaller groups of usually less than 10 individuals (Ford and Ellis 1999, Baird 2000, Baird and Whitehead 2000), display a more fluid social organization, and have diets consisting largely of other marine mammals (Baird and Dill 1996, Ford et al. 1998, Saulitis et al. 2000). They also move greater distances and tend to have larger home ranges than residents (Goley and Straley 1994, Dahlheim and Heyning 1999, Baird 2000). Morphologically, the dorsal fins of transients are straighter at the tip than in residents and offshores (Ford and Ellis 1999, Ford et al. 2000). Two patterns of saddle pigmentation are recognized (Baird and Stacey 1988). Genetic investigations using both nuclear DNA and mtDNA have found significant genetic differences between transients and other killer whale forms, confirming the lack of interbreeding (Stevens 1989, Hoelzel and Dover 1991, Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001, Hoelzel 2004, Leduc and Taylor 2004). These studies also indicate that three genetically distinct assemblages of transient killer whales exist in the northeastern Pacific. These are identified as 1) west coast transients, which occur from southern California to southeastern Alaska (Figure 4); 2) Gulf of Alaska transients, which inhabit the Gulf of Alaska, Aleutians, and Bering Sea (although significant genetic differences may exist within the population [Angliss, in prep.]); and 3) the AT1 pod, which occurs in Prince William Sound and the Kenai Fjords in the northern Gulf of Alaska and has been designated as a depleted stock with no more than eight whales remaining (Ford and Ellis 1999, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001, National Marine Fisheries Service 2003a; C. O. Matkin, unpubl. data). Genetic evidence suggests there is little or no interchange of members among these populations (Barrett-Lennard and Ellis 2001).

Offshore Killer Whales

Due to a scarcity of sightings, much less information is available for the offshore killer whale population, which was first identified in the late 1980s (Ford et al. 1992, 1994, Walters et al. 1992). Offshores have the largest geographic range of any killer whale community in the northeastern Pacific. Records are distributed from southern California to Alaska (Figure 4), including many from western Vancouver Island and the Queen Charlotte Islands (Ford and Ellis 1999, Krahn et al. 2002). Recent data from Alaska has extended the population’s range to the western Gulf of Alaska and eastern Aleutians (M. E. Dahlheim, pers. comm.). Offshore killer whales usually occur 15 km or more offshore, but also visit coastal waters and occasionally enter protected inshore waters. Sightings have been made up to 500 km off the Washington coast (Krahn et al. 2002). Animals typically congregate in groups of 20-75 animals and are presumed to feed primarily on fish. Intermixing with residents and transients has not been observed. Genetic analyses indicate that offshore killer whales are reproductively isolated from other forms, but are most closely related to the southern residents (Hoelzel et al. 1998, Barrett-Lennard

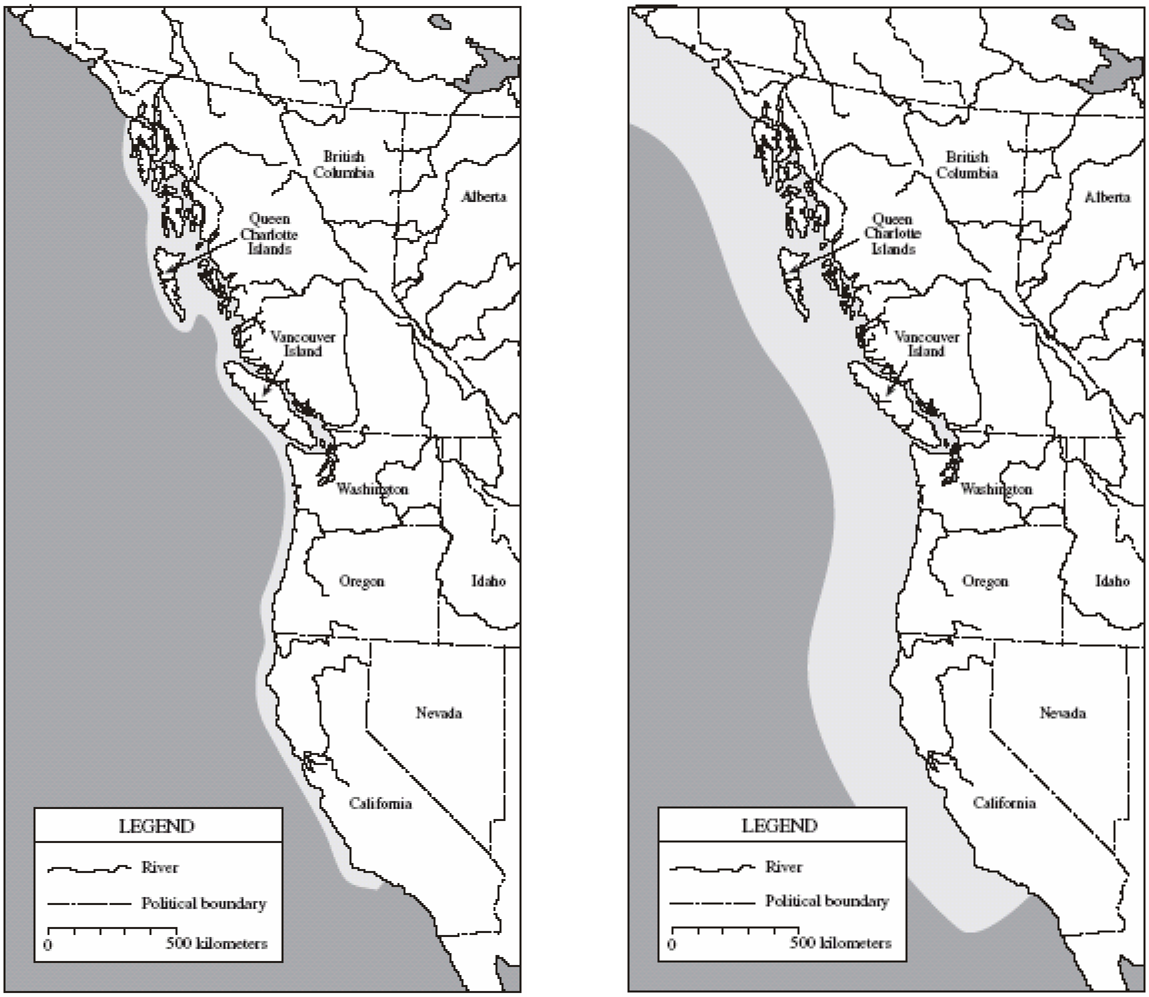


Figure 4. Geographic ranges (light shading) of the west coast transient (left) and offshore (right) killer whale populations in the northeastern Pacific. The western pelagic boundary of the ranges is ill-defined. The northern range of the offshore population extends westward to the eastern Aleutian Islands.

and Ellis 2001). Offshores are thought to be slightly smaller in body size than residents and transients, and have dorsal fins and saddle patches resembling those of residents (Walters et al. 1992, Ford et al. 2000).

Naming Systems of Killer Whales in the Northeastern Pacific

As previously noted, killer whales are individually recognizable by the unique markings and shapes of their dorsal fin, saddle patch, and eye patches. In the northeastern Pacific, researchers use a variety of alphanumeric naming systems to maintain sighting records and other data for individual whales in each community. For southern resident whales, animals are assigned their own alphanumeric names, based on their pod and the sequence in which they were identified (Ford et al. 2000). Thus, the southern resident known as "L7" was the seventh member to be documented in L pod. Similar naming systems have been applied to each of the region's other killer whale communities (e.g., Dahlheim 1997, Dahlheim et al. 1997, Matkin et al. 1999a), but these may or may not be standardized among researchers. Thus, individual whales sighted in multiple areas may have more than one name (e.g., Ford and Ellis 1999).

NATURAL HISTORY

Social Organization

Killer whales are highly social animals that occur primarily in groups or pods of up to 40-50 animals (Dahlheim and Heyning 1999, Baird 2000). Mean pod size varies among populations, but often ranges from 2 to 15 animals (Kasuya 1971, Condy et al. 1978, Mikhalev et al. 1981, Braham and Dahlheim 1982, Dahlheim et al. 1982, Baird and Dill 1996). Larger aggregations of up to several hundred individuals occasionally form, but are usually considered temporary groupings of smaller social units that probably congregate near seasonal concentrations of prey, for social interaction, or breeding (Dahlheim and Heyning 1999, Baird 2000, Ford et al. 2000). Single whales, usually adult males, also occur in many populations (Norris and Prescott 1961, Hoelzel 1993, Baird 1994). Differences in spatial distribution, abundance, and behavior of food resources probably account for much of the variation in group size among killer whale populations. For example, sympatric populations of resident and transient whales in Washington and British Columbia vary substantially in average pod size. The larger groups of residents may be better suited for detecting schools of fish, enabling individual members to increase food consumption (Ford et al. 2000). In contrast, transients forage in small groups on wary and patchily distributed marine mammals and are presumably able to maximize their per capita energy intake through reduced competition over food (Baird and Dill 1996, Ford and Ellis 1999, Baird and Whitehead 2000).

The age and sex structure of killer whale social groups has been reported for populations at several locations. The southern and northern resident communities combined were comprised of 19% adult males, 31% adult females, and 50% immature whales of either sex in 1987 (Olesiuk et al. 1990a). Nearly identical age and sex cohorts were present among the southern Alaska residents in 2001, with 19% of the animals being adult males, 24% reproductive females, 7% post-reproductive females, and 51% juveniles (Matkin et al. 2003). For southern oceans, Miyazaki (1989) found that 16% of populations were adult males, 8% were adult females with calves, and 76% were immatures and adult females without calves. At Marion Island in the southern Indian Ocean, 29% of the population were adult males, 21% were adult females, 8% were calves, 25% were subadults, and 17% were unidentified (Condy et al. 1978).

Some of the most detailed studies of social structure in killer whales have been made in British Columbia, Washington, and Alaska during the past few decades, with much information available on group size, structure, and stability, and vocal traits (Ford 1989, 1991, Bigg et al. 1990, Baird and Dill 1996, Matkin et al. 1999b, Baird 2000, Baird and Whitehead 2000, Ford et al. 2000, Miller and Bain 2000, Yurk et al. 2002). Social organization in this region is based on maternal kinship and may be characteristic of killer whale populations throughout the world (Ford 2002).

Residents. Four levels of social structure have been identified among resident killer whales. The basic and most important social unit is the matriline, which is a highly stable hierarchical group of individuals linked by maternal descent (Baird 2000, Ford et al. 2000, Ford 2002, Ford and Ellis 2002). A matriline is usually composed of a female, her sons and daughters, and offspring of her daughters, and contains one to 17 (mean = 5.5) individuals spanning one to four (mean = 3) generations. Members maintain extremely strong bonds and individuals seldom separate from the group for more than a few hours. Permanent dispersal of individuals from resident matrilines has never been recorded (Bigg et al. 1990, Baird 2000, Ford et al. 2000, Barrett-Lennard and Ellis 2001). Matriarchal females likely hold important social knowledge that guides the behavior of individual matrilines (Boran and Heimlich 1999, McComb et al. 2001).

Groups of related matrilines are known as pods. Matrilines within pods share a common maternal ancestor from the recent past, making them more closely related to one another than to those of other pods (Baird 2000, Ford et al. 2000). Pods are less cohesive than matrilines and member matrilines may travel apart for periods of weeks or months. Nonetheless, matrilines associate more often with others from their pod than with matrilines from other pods. Most pods are comprised of one to four matrilines, but one southern resident pod (L pod) holds 12 matrilines (Table 1). Resident pods contain two to 59 whales (mean = 16) (Bigg et al. 1987, Ford et al. 2000, Ford 2002, Matkin et al. 2003; Center for Whale Research, unpubl. data). Gradual changes in pod structure and cohesion occur through time with the deaths and births of members, as seen after the death of one matriarchal female, which appeared to prompt the fragmentation of her matriline (Ford et al. 2000). Such changes in association patterns caused some observers to believe that L pod had broken into three smaller pods during the 1980s (Hoelzel 1993). Within pods, some researchers recognize the existence of an intermediate type of association known as the subpod, which is defined as a grouping of matrilines that spends more than 95% of their time together (Baird 2000).

Clans are the next level of social structure and are composed of pods with similar vocal dialects and a common but older maternal heritage (Ford 1991, Ford et al. 2000, Yurk et al. 2002). Those pods with similar dialects are presumably more closely related to one another than those with greater differences in their dialects (Ford 1991). However, vocalizations known as pulsed calls are not shared between different clans, indicating a lack of recent common ancestry between clans. Clans overlap in their geographic ranges and pods from different clans frequently intermingle.

Pods (and clans) that regularly associate with one another are known as communities, which represent the highest level of social organization in resident killer whale societies (Ford et al. 2000, Ford 2002). Four communities (southern, northern, southern Alaska, and western Alaska) of resident whales exist in the northeastern Pacific. Communities are based solely on association patterns rather than maternal relatedness or acoustic similarity. Ranges of neighboring communities partially overlap and member pods may or may not associate on an occasional basis with those from other communities (Baird 2000). The southern resident community is comprised of three pods and one clan (J), whereas the northern resident community has 16 pods in three clans (A, G, and R) (Table 1, Ford et al. 2000).

Table 1. Social hierarchy and pod sizes of southern and northern resident killer whales in Washington and British Columbia (Ford et al. 2000; Center for Whale Research, unpubl. data).

Community	Clan	Pod[a]	Matrilines	No. of members per pod[b]
Southern residents	J	J	J2, J8, J9, J16	23
	J	K	K3, K4, K7, K18	21
	J	L	L2, L4, L9, L12, L21, L25, L26, L28, L32, L35, L37, L45	44
			Total	88
Northern residents	A	A1	A12, A30, A36	16
	A	A4	A11, A24	11
	A	A5	A8, A9, A23, A25	13
	A	B1	B7	7
	A	C1	C6, C10	14
	A	D1	D7, D11	12
	A	H1	H6	9
	A	I1	I1	8
	A	I2	I22	2
	A	I18	I17, I18	16
	G	G1	G3, G4, G17, G18, G29	29
	G	G12	G2, G12	13
	G	I11	I11, I15	22
	G	I31	I31	12
	R	R1	R2, R5, R9, R17	29
	R	W1	W3	3
			Total	216

[a] Southern resident pods are also known as J1, K1, and L1 pods (Ford et al. 2000).

[b] Pod sizes are based on annual census results from 2004 for southern residents (Center for Whale Research, unpubl. data) and from 1998 for northern residents (Ford et al. 2000).

Transients. The social organization of transients is less understood than for resident whales. Transients also occur in fairly stable maternal groups, with some associations between individual animals exceeding 15 years (Baird 2000, Baird and Whitehead 2000). Groups are thought to usually comprise an adult female and one or two of her offspring (Ford and Ellis 1999, Baird and Whitehead 2000). Male offspring typically maintain stronger relationships with their mother than female offspring, and such bonds can extend well into adulthood. Unlike residents, extended or permanent dispersal of transient offspring away from natal matrilines is common, with juveniles and adults of both sexes participating (Ford and Ellis 1999, Baird 2000, Baird and Whitehead 2000). Some males depart to become "roving" males. These individuals do not form long-term associations with other whales, but live solitarily much of the time and occasionally join groups that contain potentially reproductive females (Baird 2000, Baird and Whitehead 2000). Roving males do not associate together in all-male groups. Females that disperse from their maternal matriline appear to be more gregarious than males, but remain socially mobile (Baird and Whitehead 2000).

Transient pods are smaller than those of residents, numbering just one to four individuals (mean = 2.4) (Baird and Dill 1996, Ford and Ellis 1999, Baird and Whitehead 2000). Ford and Ellis (1999) reported that about 70% of all transient groups contained two to six animals (median = four), 17% had 7-11 animals, 10% were lone animals (these are mostly males; Baird 1994), and 3% had 12-22 individuals. Larger groups result from matrilines temporarily joining each other to forage and socialize (Baird and Dill 1995, 1996, Ford and Ellis 1999, Baird and Whitehead 2000). In comparison with resident killer whales, transient matrilines generally maintain more flexible association patterns with one another (Baird and Dill 1995, Baird 2000). However, some matrilines associate preferentially with certain other matrilines, perhaps for reasons of enhanced foraging success (Baird and Dill 1995). As in resident clans, all members of the transient community share a related acoustic repertoire, although regional differences in vocalizations have been noted (Ford 2002).

Offshores. The social structure of offshore killer whales has not been studied in detail. These whales usually occur in large groups of 20-75 animals, but aggregations of up to 200 whales have been recorded (Walters et al. 1992, Ford et al. 2000, Krahn et al. 2002, 2004a). Membership patterns within groups appear to be dynamic, with considerable interchange of animals noted between sightings (K. C. Balcomb, unpubl. data).

Vocalizations

Vocal communication is particularly advanced in killer whales and is an essential element of the species' complex social structure. Like all dolphins, killer whales produce numerous types of vocalizations that are useful in navigation, communication, and foraging (Dahlheim and Awbrey 1982, Ford 1989, Barrett-Lennard et al. 1996, Ford et al. 2000, Miller 2002, Miller et al. 2004). Sounds are made by air forced through structures in the nasal passage and are enhanced and directed forward by a fatty enlargement near the top of the head, known as the melon. Most calls consist of both low- and high-frequency components (Bain and Dahlheim 1994). The low-frequency component is relatively omnidirectional, with most energy directed forward and to the sides (Schevill and Watkins 1966). A fundamental tone between 250-1,500 Hz and harmonics ranging to about 10 kHz are present in this component. Most of the energy in the high-frequency component is beamed directly ahead of the animal. This component has a fundamental tone between 5-12 kHz and harmonics ranging to over 100 kHz (Bain and Dahlheim 1994).

Newborn calves produce calls similar to adults, but have a more limited repertoire (Dahlheim and Awbrey 1982). As young animals mature, complete call repertoires are most likely developed through vocal imitation and learning from association with closely related animals rather than being genetically inherited (Bowles et al. 1988, Bain 1989, Ford 1989, 1991, Miller and Bain 2000, Yurk et al. 2002). Regional differences in call structure and vocalization patterns have been recorded from the North Pacific, North Atlantic, and Antarctica (Jehl et al. 1980, Thomas et al. 1981, Awbrey et al. 1982, Strager 1995).

Killer whales produce three categories of sounds: echolocation clicks, tonal whistles, and pulsed calls (Ford 1989). Clicks are brief pulses of ultrasonic sound given singly or more often in series known as click trains. They are used primarily for navigation and discriminating prey and other objects in the surrounding environment, but are also commonly heard during social interactions and may have a communicative function (Barrett-Lennard et al. 1996). Barrett-Lennard et al. (1996) suggested that killer whales share information obtained from echolocation, but further clarification of this possible function is needed (Baird 2000). Individual clicks are highly variable in structure, lasting from 0.1 to 25 milliseconds and containing a narrow to broad range of frequencies that usually range from 4-18 kHz, but extend up to 50-85 kHz (Diercks et al. 1973, Awbrey et al. 1982, Ford 1989, Barrett-Lennard et al. 1996, Au et al. 2004). Most click trains last 2-8 seconds and have repetition rates of 2-50 clicks per second, but some exceed 10 seconds or hold as many as 300 clicks per second (Jehl et al. 1980, Ford 1989, Barrett-Lennard et al. 1996, Ford et al. 2000). Slower click trains are probably used for navigation and orientation on more distant objects, such as other whales and features on the seafloor, whereas rapid click rates appear to be used for investigating objects within 10 m (Ford 1989).

Most whistles are tonal sounds of a fundamental frequency with the addition of several harmonics (Thomsen et al. 2001). Whistles have an average dominant frequency of 8.3 kHz (range = 3-18.5 kHz), an average bandwidth of 4.5 kHz (range = 0.5-10.2 kHz), and an average of 5.0 frequency modulations per whistle (range = 0-71 frequency modulations) (Thomsen et al. 2001). Mean duration is 1.8 seconds (range = 0.06-18.3 seconds). Whistles are the primary type of vocalization produced during close-range social interactions (Thomsen et al. 2002). They are given infrequently during foraging and most types of traveling.

Pulsed calls are the most common type of vocalization in killer whales and resemble squeaks, screams, and squawks to the human ear. Most calls are highly stereotyped and distinctive in structure, being characterized by rapid changes in tone and pulse repetition rate, with some reaching up to 4,000 or more pulses per second (Jehl et al. 1980, Ford 1989). Duration is usually less than two seconds. Call frequencies often fall between 1-6 kHz, but may reach more than 30 kHz. Three categories of pulsed calls are distinguishable: discrete, variable, and aberrant (Ford 1989). Discrete calls have received considerable study and are especially noteworthy because they are used repetitively and have stable group-specific structural traits. Discrete calls are the predominant sound type during foraging and traveling, and are used for maintaining acoustic contact with other group members, especially those out of visual range (Ford 1989, Ford et al. 2000, Miller 2002). Variable and aberrant calls are given more frequently after animals join together and interact socially. Representative sound spectrograms of discrete calls are presented in Ford (1989, 1991).

The vocal repertoires of killer whale pods are comprised of specific numbers and types of repetitive discrete calls, which together are known as a dialect (Ford 1991). Dialects are complex and stable over time, and are unique to single pods. Call patterns and structure are also distinctive within matrilines (Miller and Bain 2000). Individuals likely learn their dialect through contact with their mother and other pod members (Ford 1989, 1991, Miller and Bain 2000). Dialects are probably an important means of maintaining group identity and cohesiveness. Similarity in dialects likely reflects the degree of relatedness between pods, with variation building through time as matrilines and pods grow and split (Ford 1989, 1991, Bigg et al. 1990, Miller and Bain 2000). Researchers have thus far been unable to determine whether specific calls have particular meanings or are associated with certain activities. Deecke et al.

(2000) reported that some calls undergo gradual modification in structure over time, probably due to cultural drift, maturational effects, or some combination thereof.

Dialects of resident killer whale pods contain seven to 17 (mean = 11) distinctive call types (Ford 1991). Transient dialects are much different, having only four to six discrete calls, none of which are shared with residents (Ford and Ellis 1999). All members of the west coast transient community possess the same basic dialect, as would be expected due to this population's fluid social system, although some minor regional variation in call types is evident (Ford and Ellis 1999). Preliminary research indicates that offshore killer whales have group-specific dialects unlike those of residents and transients (Ford et al. 2000).

Hearing and Other Senses

As with other delphinids, killer whales hear sounds through the lower jaw and other portions of the head, which transmit the sound signals to receptor cells in the middle and inner ears (Møhl et al. 1999, Au 2002). Killer whale hearing is the most sensitive of any odontocete tested thus far. Hearing ability extends from 1 to at least 120 kHz, but is most sensitive in the range of 18-42 kHz (Szymanski et al. 1999). The most sensitive frequency is 20 kHz, which corresponds with the approximate peak energy of the species' echolocation clicks (Szymanski et al. 1999). This frequency is lower than in many other toothed whales. Hearing sensitivity declines below 4 kHz and above 60 kHz. Killer whale vision is also considered well developed (White et al. 1971).

Swimming and Diving Behavior

The typical swimming pattern of foraging and traveling killer whales is a sequence of three to five shallow dives lasting 10-35 seconds each followed by a long dive, with surface blows of 3-4 seconds occurring after each dive (Erickson 1978, Morton 1990, Ford and Ellis 1999). This pattern is typically synchronized among pod members. Dive cycles in resident whales average about 3-5 minutes in total length and have a long dive usually lasting 2-4 minutes (Morton 1990; Ford and Ellis 1999; Baird et al. in prep.). Transients have longer dive cycles, with long dives averaging 4-7 minutes (range = 1-17 minutes) (Erickson 1978, Morton 1990, Ford and Ellis 1999). Cycle lengths and respiration rates vary with activity level (Erickson 1978, Ford 1989, Kriete 1995).

While in the Georgia Basin, the southern residents spend 95% of their time underwater, nearly all of which is between the surface and a depth of 30 m (Baird 2000; Baird et al. 2003, in prep.). During a study of 28 whales tagged with time-depth recorders from 1993-2002, Baird et al. (2003, in prep.) reported an average of about 0.7 to two dives per hour made below 30 m, with such dives occurring more often during daytime. These represented 5% of all dives and occupied less than 2.5% of an animal's total dive time. During the day, dives greater than 150 m deep were made on average about once every five hours. Overall dive rates were greater during the day than at night, but did not differ among pods or with age (Baird et al. in prep.). Dive rates below 30 m were also greater in adult males than adult females, with adult males diving deeper than 100 m more than twice as often as adult females. Maximum dive depths for all ages averaged 141 m, with 10 study animals exceeding depths of 190 m. Three-year-old whales reached mean maximum depths of 134 m, indicating that diving skills are developed fairly early in life (Baird et al. in prep.). Much less is known about the diving behavior of transients, but one similarly tagged individual spent more than 66% of its time at depths between 20 and 60 m (Baird 1994). The deepest dives reported for killer whales are 264 m by a southern resident (Baird et al. in prep.) and 260 m by a trained animal (Bowers and Henderson 1972). However, Baird et al. (2003) speculated that the southern residents are probably capable of diving to the deepest portions of the core inland waters of their summer range, which reach approximately 330 m.

Killer whales normally swim at speeds of 5-10 km per hour, but can attain maximum speeds of 40 km per hour (Lang 1966, Erickson 1978, Kruse 1991, Kriete 1995, Williams et al. 2002a). Descent and ascent rates of diving animals typically average 4-6.5 km per hour, or 1.1-1.8 m per second, but can sometimes reach velocities of 22-29 km per hour, or 6-8 m per second (Baird 1994). Bursts of speed during dives commonly occur when prey are chased (Baird et al. 2003). Swimming speeds are greater during the day than at night for the southern residents (Baird et al. in prep.).

Diet and Foraging

As top-level predators, killer whales feed on a variety of marine organisms ranging from fish to squid to other marine mammal species. Some populations have specialized diets throughout the year and employ specific foraging strategies that reflect the behavior of their prey. Such dietary specialization has probably evolved in regions where abundant prey resources occur year-round (Ford 2002). Cooperative hunting, food sharing, and innovative learning are other notable foraging traits in killer whales (Smith et al. 1981, Lopez and Lopez 1985, Felleman et al. 1991, Hoelzel 1991, Jefferson et al. 1991, Hoelzel 1993, Similä and Ugarte 1993, Baird and Dill 1995, Boran and Heimlich 1999, Guinet et al. 2000, Pitman et al. 2003). Cooperative hunting presumably increases hunting efficiency and prey capture success of group members, and may also enhance group bonds. Additionally, group living facilitates knowledge of specialized hunting skills and productive foraging areas to be passed traditionally from generation to generation (Lopez and Lopez 1985, Guinet 1991, Guinet and Bouvier 1995, Ford et al. 1998). Some foraging styles require extensive practice and learning (e.g., Guinet 1991).

Dietary information was formerly derived primarily through examination of stomach contents from stranded whales or those killed during commercial whaling operations, but in recent years, direct observations of feeding behavior have added much new data on the species' food habits. Killer whales are the only cetacean to routinely prey on marine mammals, with attacks documented on more than 35 mammal species, including species as large as blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), and sperm whales (*Physeter macrocephalus*) (Tomilin 1957, Tarpy 1979, Hoyt 1990, Jefferson et al. 1991, Dahlheim and Heyning 1999, Pitman et al. 2001). Pinnipeds and cetaceans are major prey items for some populations (Zenkovich 1938, Tomilin 1957, Rice 1968, Hoelzel 1991, Jefferson et al. 1991, Baird and Dill 1996, Ford et al. 1998, Dahlheim and Heyning 1999). Because killer whales probably represent the most important predators of many marine mammals, their predation has presumably been a major evolutionary influence on the life history of these prey species (Jefferson et al. 1991, Corkeron and Conner 1999, Pitman et al. 2001, Deecke et al. 2002). Fish (including tuna, rays, and sharks) and squid are other major foods, with penguins, other seabirds, and sea turtles also taken (Tomilin 1957, Nishiwaki and Handa 1958, Caldwell and Caldwell 1969, Condy et al. 1978, Ivashin 1982, Hoyt 1990, Fertl et al. 1996, Similä et al. 1996, Ford et al. 1998, Dahlheim and Heyning 1999, Ford and Ellis 1999, Visser 1999b, Aguiar dos Santos and Haimovici 2001, Ainley 2002, Visser and Bonoccorso 2003, Pitman and Dutton 2004, Reyes and García-Borboroglu 2004). Killer whales also may steal fish from longlining vessels (Dahlheim 1988, Yano and Dahlheim 1995a, 1995b, Secchi and Vaske 1998, Visser 2000a), scavenge the discarded bycatch of fisheries operations (Sergeant and Fisher 1957, Dahlheim and Heyning 1999), and feed on harpooned whales under tow by whaling ships (Scammon 1874, Heptner et al. 1976, Hoyt 1990). There are no verified records of killer whales killing humans. In general, populations specializing on either fish or marine mammals occur at higher latitudes, whereas populations at lower latitudes tend to have generalist diets (Forney and Wade in press).

Residents. Fish are the major dietary component of resident killer whales in the northeastern Pacific, with 22 species of fish and one species of squid (*Gonatopsis borealis*) known to be eaten (Scheffer and Slipp 1948, Ford et al. 1998, 2000, Saulitis et al. 2000). Observations from this region indicate that salmon are clearly preferred as prey. Existing dietary data for southern and northern resident killer whales should be considered preliminary. Most published information originates from a single study (Ford et al. 1998) in British Columbia, including southeastern Vancouver Island, that focused primarily on northern residents, relied on several field techniques susceptible to bias (e.g., surface observations and scale sampling), and reported on a relatively small sample of observations. Of the 152 feeding records and apparent predation events involving fish in this study, only 27 (18%) observations came from southern residents. With these limitations in mind, salmon were found to represent 96% of the prey during the spring, summer, and fall. Chinook salmon (*Oncorhynchus tshawytscha*) were selected over other species, comprising 65% of the salmonids taken. This preference occurred despite the much lower numerical abundance of chinook in the study area in comparison to other salmonids and is probably related to the species' large size, high fat and energy content (see Salmon Body Composition), and year-round occurrence in the area. Other salmonids eaten in smaller amounts included pink (*O. gorbuscha*, 17% of the diet), coho (*O. kisutch*, 6%), chum (*O. keta*, 6%), sockeye (*O. nerka*, 4%), and steelhead (*O. mykiss*, 2%) salmon. Stomach content analyses (n = 8) corroborated the preference for chinook. Intensive scale sampling in 2003 and 2004 has documented more than 200 additional feeding records for the northern residents (J. K. B. Ford, unpubl. data). This work confirms the overall preference of these whales for chinook salmon during the summer and fall, but also revealed extensive feeding on chum salmon in the fall. These combined data may underestimate the extent of feeding on bottom fish (Baird 2000). Species such as rockfish (*Sebastes* spp.), Pacific halibut (*Hippoglossus stenolepis*), a number of smaller flatfish, lingcod (*Ophiodon elongatus*), and greenling (*Hexagrammos* spp.) are likely consumed on a regular basis (Ford et al. 1998). Pacific herring (*Clupea pallasi*) also contribute to the diet. The conclusion that the southern residents feed largely on salmon is supported by the toxicology analyses of Krahn et al. (2002), who determined that the ratios of DDT (and its metabolites) to various PCB compounds in the whales correspond with those of Puget Sound salmon rather than those of other fish species. Resident whales have been seen to harass porpoises and harbor seals, but never kill and eat them (Ford et al. 1998). Little is known about the winter and early spring foods of southern and northern residents or whether individual pods have specific dietary preferences. Future research on the food habits of both populations may find meaningful deviations from the pattern described above. Data gathered thus far for the southern Alaska residents also indicate that salmon are heavily preferred as prey, with extensive use of coho salmon recorded in Prince William Sound (Saulitis et al. 2000) and regular consumption of chinook salmon in Kenai Fjords (Matkin et al. 2003). However, these observations suffer from the same biases reported by Ford et al. (1998) and even smaller sample sizes. Western North Pacific resident killer whales also appear to target salmon as prey (V. Burkanov, pers. comm. in Krahn et al. 2004a).

Resident whales spend about 50-67% of their time foraging (Heimlich-Boran 1988, Ford 1989, Morton 1990, Felleman et al. 1991). Groups of animals often disperse over several square kilometers while searching for salmon, with members moving at roughly the same speed (range of 3-10 km/hr, mean = 6 km/hr) and direction (Ford 1989, 2002, Ford et al. 1998). Foraging episodes usually cover areas of 3-10 km^2 and last 2-3 hours, but may extend up to 7 hours. Individual salmon are pursued, captured, and eaten by single animals or small subgroups, usually a mother and her young offspring (Scheffer and Slipp 1948, Jacobsen 1986, Osborne 1986, Felleman et al. 1991, Ford 1989, Ford et al. 1998). Foraging whales commonly make two or three brief shallow dives, followed by a longer dive of 1-3 minutes (Ford et al. 2000). Several whales may occasionally work together to corral fish near the shore, but coordinated encirclement of prey has not been observed in Washington or British Columbia (Ford 1989, Ford et al. 1998). The large sizes of resident pods may benefit members by improving the success rate of locating scattered salmon (Heimlich-Boran 1988, Bigg et al. 1990, Hoelzel 1993). Prey are detected through a combination of echolocation and passive listening (Barrett-Lennard et al. 1996), whereas vision and echolocation are probably used during prey capture. Foraging animals produce rapid series of evenly spaced echolocation clicks, but whistles and pulsed calls are also emitted during this activity (Ford 1989). Echolocation signals allow salmon to be detected out to distances of about 100 m (Au et al. 2004). More foraging may occur during the day than at night (Baird et al. in prep.), although inshore feeding possibly increase at night (Scheffer and Slipp 1948). There is some evidence that adult resident males forage differently than females and immatures, possibly because their larger size makes them less maneuverable in shallow waters (Baird 2000). Adult males have been noted to hunt in deeper waters than females, dive more deeply than females, and spend more time foraging on the edges of pods (Ford et al. 1998; Baird et al. in prep.). Females and subadults occasionally attempt to capture salmon hiding in rock crevices near shore, a behavior not seen in adult males. Baird et al. (in prep.) reported no significant differences in the diving behavior of the three southern resident pods, suggesting that each hunts for prey in a similar manner.

Transients. The dietary habits of transients and other mammal-eating killer whale populations are summarized in Jefferson et al. (1991), Ford and Ellis (1999), and Wiles (2004). Unlike resident whales, transients feed almost entirely on marine mammals. Harbor seals are the most important prey item in much of the northeastern Pacific, but other species are regularly taken as well, including Dall's porpoises (*Phocenoides dalli*), harbor porpoises, Steller's sea lions (*Eumetopias jubatus*), and California sea lions (*Zalophus californianus*) (Matkin and Saulitis 1994, Baird and Dill 1996, Ford et al. 1998, Saulitis et al. 2000, Heise et al. 2003). Predation on a variety of other marine mammals, including large whales, is generally less frequent (Jefferson et al. 1991, Baird and Dill 1996, Ford et al. 1998), although migrating gray whales (*Eschrichtius robustus*) with calves are apparently routinely attacked (Andrews 1914, Morejohn 1968, Rice and Wolman 1971, Jefferson et al. 1991, Goley and Straley 1994, Ford et al. 1998, Ford 2002). Seabirds are also occasionally eaten, but fish are never consumed.

Transients usually forage in smaller groups than residents, with mean group size numbering from three to five whales depending on the prey species (Baird and Dill 1996, Ford et al. 1998). Transients are stealthy hunters and often rely on surprise to capture unsuspecting prey. Unlike residents, they are much quieter while foraging, which probably allows them to avoid acoustical detection by their wary mammalian prey. (Morton 1990, Felleman et al. 1991, Barrett-Lennard et al. 1996, Ford and Ellis 1999). Transients may instead rely heavily on passive listening to detect the sounds of swimming prey (Barrett-Lennard et al. 1996). Vision may also be useful (Baird 2000). Transients spend 60-90% of daylight hours foraging and commonly hunt in both nearshore and open-water habitats (Heimlich-Boran 1988, Morton 1990, Baird and Dill 1995, Ford and Ellis 1999).

A recent highly controversial theory proposes that predation by mammal-eating killer whales, possibly transients, may have been responsible for a series of precipitous population declines in harbor seals, northern fur seals (*Callorhinus ursinus*), Steller's sea lions, and sea otters (*Enhydra lutris*) in southwestern Alaska between the 1960s and 1990s (Estes et al. 1998, Hatfield et al. 1998, Doroff et al. 2003, Springer et al. 2003). Such predation may have resulted after heavy commercial whaling decimated baleen and sperm whale numbers in the North Pacific after World War II, perhaps causing at least some killer whales to shift to other prey species (Springer et al. 2003). A recent increase in predation on belugas (*Delphinapterus leucas*) by probable transients in Cook Inlet, Alaska, may be due to similar reasons (Shelden et al. 2003).

Offshores. Little is known about the diets of offshore killer whales. They are suspected to feed primarily on fish and squid, based on their frequent use of echolocation, large group sizes, the stomach contents of a few animals, and very limited testing of fatty acid concentrations (Ford et al. 2000, Heise et al. 2003, Herman et al. 2004). Prey may include sharks and migratory fish (Krahn et al. 2004a). However, preliminary analyses of stable isotopes and organochlorine contaminants in offshores suggest the possibility that marine mammals are also eaten (Herman et al. 2004).

Food requirements. Captive killer whales consume about 3.6-4% of their body weight daily (Sergeant 1969, Kastelein et al. 2000). Food intake in captive animals gradually increases from birth until about 20 years of age (Kriete 1995, Kastelein et al. 2003). For example, a captive female ate about 22 kg of fish per day at one year of age, 45 kg per day at 10 years of age, and about 56 kg per day at 18 years of age (Kastelein and Vaughan 1989, Kastelein et al. 2000). Food consumption has also been noted to increase among captive females late in pregnancy or lactating (Kriete 1995, Kastelein et al. 2003). Due to their greater activity levels, wild killer whales presumably have greater food demands than captive individuals (Kastelein et al. 2003). The energy requirements of killer whales are about 85,000 kcal per day for juveniles, 100,000 kcal per day for immatures, 160,000 kcal per day for adult females, and 200,000 kcal per day for adult males (Osborne 1999). Based on these values and an average size value for five salmon species combined, Osborne (1999) estimated that adults must consume about 28-34 adult salmon daily and that younger whales (<13 years of age) need 15-17 salmon daily to maintain their energy requirements. Extrapolation of this estimate indicates that the southern resident population eats about 750,000-800,000 adult salmon annually (Osborne 1999). Baird and Dill (1996) reported a somewhat higher mean energy intake of 62 kcal/kg/day among transient whales.

Other Behavior

In addition to foraging, killer whales spend significant amounts of time traveling, resting, and socializing (Baird and Dill 1995, Ford 2002, Saulitis et al. 2000). Limited evidence from radio-tracking and acoustic monitoring indicates that most behavior patterns are similar during day and night (Erickson 1978, Osborne 1986). By comparison, examination of diving behavior and swim speeds suggests killer whales are more active in the daytime (Baird et al. in prep.).

Traveling. Whales swimming in a constant direction at a slow, moderate, or rapid pace without feeding are considered to be traveling (Jacobsen 1986, Baird and Dill 1995, Ford 1989, Ford and Ellis 1999, Ford et al. 2000). This behavior is usually seen among animals moving between locations, such as desirable feeding areas. Speeds of about 10 km/hr (range = 4-20 km/hr) are maintained, which is usually significantly faster than during foraging. Traveling whales often line up abreast in fairly tight formations and commonly surface and dive in synchrony, with individuals occasionally jumping entirely out of the water. Resident animals are usually much more vocal while traveling than transients (Barrett-Lennard et al. 1996), but may at times be silent. In Washington and British Columbia, traveling occupies about 15-31% of the total activity budget of transients, but only about 4-8% of the time of northern residents (Ford 1989, Morton 1990, Baird and Dill 1995). Southern residents reportedly spend more time traveling than northern residents (Heimlich-Boran 1988), perhaps because of longer distances between their feeding sites (Ford et al. 2000).

Resting. This behavior often follows periods of foraging. In resident groups, whales usually gather together abreast in a tight formation, with animals diving and surfacing in subdued unison (Jacobsen 1986, Osborne 1986, Ford 1989, Baird and Dill 1995, Ford et al. 2000). Individuals often arrange themselves according to matriline or pod, and offspring usually swim near or touching their mother. Forward motion is slow (mean = 3 km/hr) or stops entirely. Dives and surfacings become characteristically regular, with a series of several short shallow surfacings lasting 2-3 minutes followed by a longer dive of 2-5 minutes. Resting whales are usually silent, except for occasional vocalizations. Resting periods average about 2 hours, but may last from 30 minutes to 7 hours (Osborne 1986, Ford 1989). Transient whales display similar resting behavior, but spend only 2-7% of their time resting, compared to 10-21% for residents (Heimlich-Boran 1988, Ford 1989, Morton 1990, Baird and Dill 1995, Ford and Ellis 1999, Saulitis et al. 2000).

Socializing. Killer whales perform numerous displays and interactions that are categorized as socializing behaviors (Ford 1989, Ford and Ellis 1999, Ford et al. 2000). During socializing, all members of a pod may participate or just a few individuals may do so while others rest quietly at the surface or feed. Socializing behaviors are seen most frequently among juveniles and may represent a type of play (Jacobsen 1986, Osborne 1986, Ford 1989, Rose 1992). They include chasing, splashing at the surface, spyhopping, breaching, fin slapping, tail lobbing, head standing, rolling over other animals, and playing with objects such as kelp or jellyfish. Descriptions and photographs of these behaviors are presented in Jacobsen (1986) and Osborne (1986). Wave riding occasionally takes place in the wakes of vessels and on naturally generated waves (Jacobsen 1986, Ford et al. 2000), as does bow-riding in the bow waves of boats (Dahlheim 1980). Socializing behavior may involve considerable physical contact among animals. All-male subgroups commonly engage in sexual behavior, such as penile erections and nosing of genital areas (Haenel 1986, Osborne 1986, Jacobsen 1986, Ford 1989, Rose 1992). Play and sexual behavior may help adolescents, especially males, gain courtship skills (Rose 1992). Whales become especially vocal while socializing and emit a wide range of whistles and calls heard infrequently during other activities, such as foraging and resting (Ford 1989, Barrett-Lennard et al. 1996, Thomsen et al. 2002). Residents spend about 12-15% of their time engaged in socializing (Heimlich-Boran 1988, Ford 1989, Saulitis et al. 2000). Transient whales socialize less than residents and do so most often after successful hunts (Heimlich-Boran 1988, Baird and Dill 1995, Ford and Ellis 1999, Saulitis et al. 2000).

Several differences in socializing behavior have been documented among resident killer whale communities in the northeastern Pacific (Ford 1989, Ford et al. 2000). Southern residents perform aerial displays more frequently and with greater vigor than northern residents. They also engage more often in a greeting ceremony that occurs when pods meet after being separated for a day or more (Osborne 1986, Ford et al. 2000). During this interaction, pods approach each other in two tight lines, stop for 10-30 seconds at the surface when 10-50 m apart, then merge underwater with considerable excitement, vocalizing, and physical contact. Beach rubbing, which involves whales visiting particular beaches to rub their bodies on smooth pebbles in shallow water (Jacobsen 1986), is common among northern residents, but has never been observed in southern residents or transients (Ford 1989, Ford et al. 2000). Beach rubbing also occasionally occurs among some southern Alaska residents inhabiting Prince William Sound (Matkin and Saulitis 1994, 1997). These examples are particularly illustrative of the cultural variation that can occur among these communities (Whitehead et al. 2004).

Courtship and mating. Courtship and mating behavior remains poorly documented among wild killer whales. Jacobsen (1986) reported some preliminary observations. In captive situations, males may court a particular estrous female for 5-10 days and have been noted to copulate with anestrous and pregnant females as well (Duffield et al. 1995). It is unknown whether similar behavior occurs in the wild.

Parturition. Stacey and Baird (1997) described various behaviors associated with the birth of a resident killer whale, which took place within a pod of 11-13 animals. An individual presumed to be the mother was seen making several rapid rotations at the surface during a 30-second period. Birth then apparently took place underwater and was immediately followed by three pod members lifting the newborn entirely out of the water for several seconds. Unusual swimming behavior by the group, bouts of high-speed swimming and percussive activity, and additional lifting of the calf was seen during the next two hours. Bouts of nursing take place both underwater and at the surface (Jacobsen 1986). Newborn calves in captivity have been observed to nurse an average of 32-34 times per day totaling 3.2-3.6 hours per day, with suckling bouts lasting a mean of 6.8-7.2 min (Kastelein et al. 2003).

Alloparental care. Non-reproductive female and male killer whales sometimes tend and give parental-like care to young animals that are not their own, a behavior known as alloparental care (Haenel 1986, Waite 1988). Older immatures are commonly the recipients of such care after their mothers give birth to new calves. Adult males have occasionally been seen to "baby-sit" groups of calves and juveniles (Haenel 1986, Jacobsen 1986).

Care-giving behavior. This behavior is directed at stricken individuals by other members of a group (Zenkovich 1938, Tomilin 1957, Caldwell and Caldwell 1966). Ford et al. (2000) published an account of one such incident involving a pod comprised of a male, female, and two calves in the Strait of Georgia in 1973. One of the calves was struck and severely injured by the propeller of a ferryboat. The male and female swam in closely and cradled the injured calf between them to prevent it from turning upside-down. The male regularly repositioned itself to maintain its location next to the calf.

Aggressive behavior. Aggressive interactions between killer whales are rarely witnessed. Bisther (2002) reported occasional agonistic encounters involving the displacement of one killer whale pod by another at herring feeding sites in Norway, but such behavior has never been seen in the northeastern Pacific. The parallel scarring patterns seen on the backs and dorsal fins of some killer whales are suggestive of intraspecific aggression (Scheffer 1968, Greenwood et al. 1974, Jacobsen 1986, Visser 1998). However, some of these markings possibly result instead from social interactions or the defensive responses of pinnipeds (Jacobsen 1986, Ford 1989, Dahlheim and Heyning 1999).

Interactions between transients and residents. Resident killer whales are not known to interact socially with transient whales. Baird (2000) summarized evidence that members of the two communities in fact deliberately avoid one another when traveling on intersecting routes. In 11 observations where a resident and transient group approached within several kilometers of each other, the transients responded by changing their travel direction eight times, while the residents did so in three instances. However, on eight other occasions when non-intersecting courses were involved, the groups passed within several kilometers of one another without altering their paths. Reasons for avoidance are speculative, but may be related to the usually smaller group sizes of transients or to perceived threats to vulnerable calves. Residents perhaps show less evasive behavior simply because they are unaware of the presence of transient groups, which usually forage quietly. A single aggressive interaction between the two forms has been witnessed and involved about 13 residents chasing and attacking three transients (Ford and Ellis 1999). Alaskan residents and transients similarly avoid contact with each other (Matkin and Saulitis 1997).

Movements and Dispersal

Killer whale movements are generally thought to be far ranging, but detailed information on year-round travel patterns is lacking for virtually all populations. Radio and satellite telemetry has not been used to track long-term movements because of the absence of benign techniques for restraining target animals and attaching transmitters. Researchers have instead relied on non-intrusive observational methods, especially photo-documentation and focal group following, to study population distribution and movements of individual whales. However, these techniques suffer from seasonal biases in viewing effort due to limitations in the distances that observers can travel, inclement weather, and seasonal availability of daylight (Baird 2001, Hooker and Baird 2001). A lack of photo-identification work in offshore areas is especially problematic for many monitored populations (Baird 2000). As a result, significant time gaps with few or no location data exist for all populations, including the well-studied southern and northern resident communities. This situation is probably responsible for some of the misperceptions regarding the migratory status of some populations.

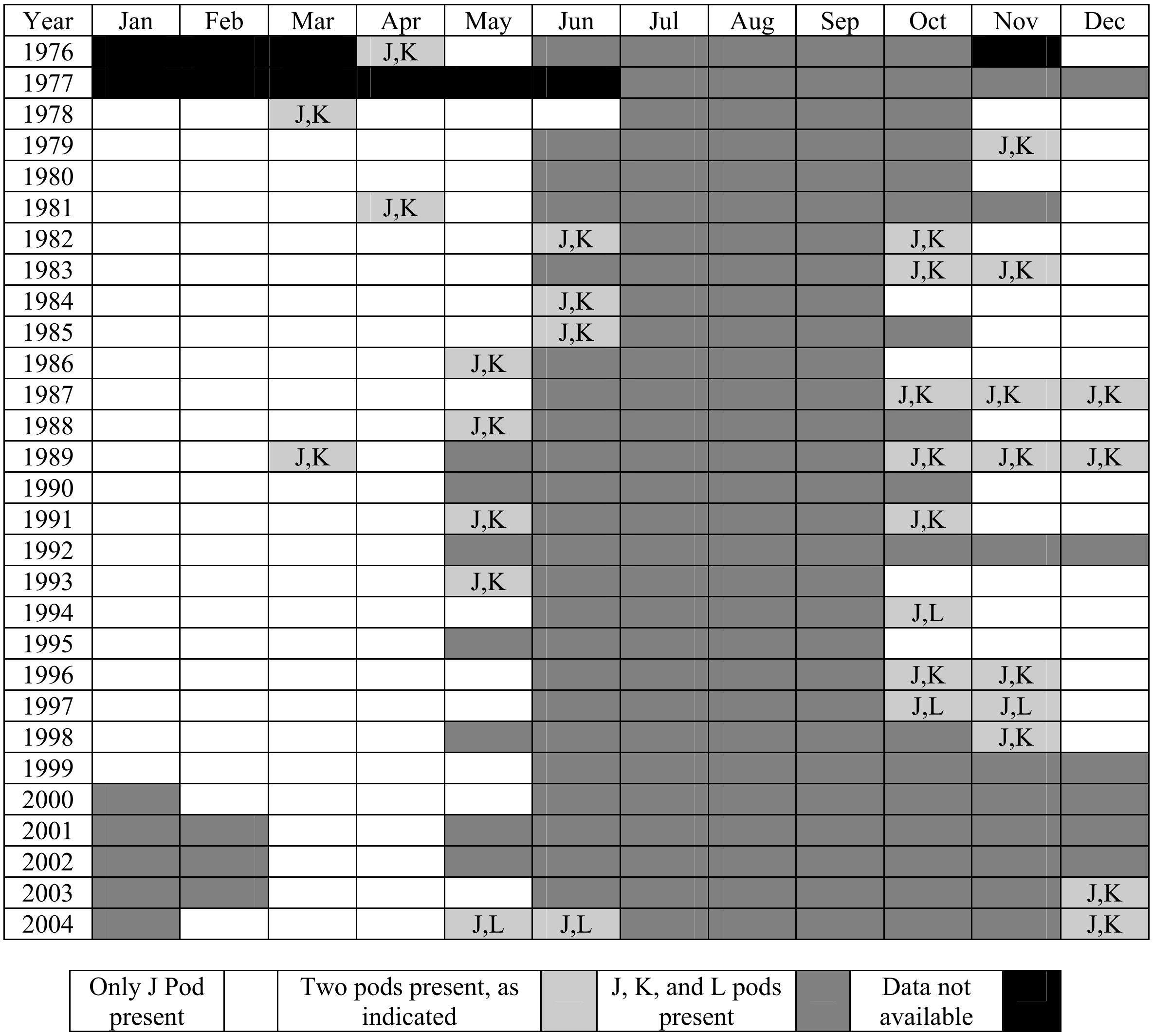
Many killer whale populations appear to inhabit relatively well-defined seasonal home ranges linked to locations of favored prey, especially during periods of high prey abundance or vulnerability, such as fish spawning and seal pupping seasons (Jefferson et al. 1991, Reeves et al. 2002). Killer whale occurrence has been tied to returning salmon in the North Pacific (Zenkovich 1938, Balcomb et al. 1980, Heimlich-Boran 1986a, 1988, Felleman et al. 1991, Nichol and Shackleton 1996), migrating herring (*Clupea harengus*) and other fish in the northeastern Atlantic (Jonsgård and Lyshoel 1970, Bloch and Lockyer 1988, Christensen 1988, Evans 1988, Similä et al. 1996), migrating rorqual whales off eastern Canada (Sergeant and Fisher 1957), minke whale presence in southern oceans (Mikhalev et al. 1981, Pitman and Ensor 2003), seal, sea lion, and elephant seal pupping sites in the southwest Indian Ocean, Argentina, and North Pacific (Zenkovich 1938, Tomilin 1957, Norris and Prescott 1961, Condy et al. 1978, Lopez and Lopez 1985, Hoelzel 1991, Baird and Dill 1995), and migrating pinnipeds in the North Pacific (Zenkovich 1938). Defended territories have not been observed around these or other food resources (Dahlheim and Heyning 1999, Baird 2000).

Clear evidence of annual north-south migrations has not been documented for any killer whale population (Baird 2001), although such movements are suspected among some animals visiting the Antarctic (Mikhalev et al. 1981, Visser 1999a, Pitman and Ensor 2003). Regional movement patterns are probably best known for populations in the northeastern Pacific and may be illustrative of movements occurring in other parts of the world. Both resident and transient killer whales have been recorded year-round in Washington, British Columbia, and Alaska (Heimlich-Boran 1988, Baird and Dill 1995, Olson 1998, Baird 2001). Many pods inhabit relatively small core areas for periods of a few weeks or months, but travel extensively at other times. Known ranges of some individual whales or pods extend from central California to the Queen Charlotte Islands off northern British Columbia (a distance of about 2,200 km) for southern residents, from southern Vancouver Island to southeastern Alaska (about 1,200 km) for northern residents, from southeastern Alaska to Kodiak Island (about 1,450 km) for southern Alaska residents, and from central California to southeastern Alaska (about 2,660 km) for west coast transients (Goley and Straley 1994; Dahlheim and Heyning 1999; Krahn et al. 2002; J. K. B. Ford and G. M. Ellis, unpubl. data). Both types of whales can swim up to 160 km per day (Erickson 1978, Baird 2000), allowing rapid movements between areas. For example, members of K and L pods once traveled a straight-line distance of about 940 km from the northern Queen Charlotte Islands to Victoria, Vancouver Island, in seven days (J. K. B. Ford and G. M. Ellis, unpubl. data). In Alaska, one resident pod journeyed 740 km in six days and another made a 1,900-km round trip during a 53-day period (Matkin et al. 1997). Transients are believed to travel greater distances and have larger ranges than residents (Goley and Straley 1994, Dahlheim and Heyning 1999, Baird 2000), as reflected by maximum home range estimates of 140,000 km^2 for transients and 90,000 km^2 for residents suggested by Baird (2000). A linear distance of 2,660 km covered by three transients from Glacier Bay, Alaska, to Monterey Bay, California (Goley and Straley 1994), is the longest recorded movement by the species.

Southern residents. Little information is available on the movements of this community prior to the early 1970s, when observers were unaware of the distinction between resident, transient, and offshore whales. Scheffer and Slipp's (1948) report suggests that killer whales in general frequented many of the same areas in Washington during the 1930s and 1940s that are currently occupied by southern residents and transients. They noted that whales, presumably southern residents, commonly moved into Tulalip Bay and the waters surrounding Camano Island during salmon and herring runs. Palo (1972) remarked that killer whales visited southern Puget Sound most often during the fall and winter. He added that the whales' preferred access route to this portion of the sound was through Colvos Passage along the west side of Vashon Island and that McNeil Island and Carr Inlet were visited annually. These sites were productive areas for salmon and herring in the 1960s (Palo 1972).

Photo-identification work and tracking by boats have provided considerable information on the ranges and movements of southern resident killer whales since the early 1970s. Ranges are best known from late spring to early autumn, when survey effort is greatest. During this period, all three southern resident pods are regularly present in the Georgia Basin (defined as the Georgia Strait, San Juan Islands, and Strait of Juan de Fuca) (Heimlich-Boran 1988, Felleman et al. 1991, Olson 1998, Osborne 1999), with K and L pods typically arriving in May or June and spending most of their time there until departing in October or November (Figure 5). However, during this season, both pods make frequent trips lasting a few days to the outer coasts of Washington and southern Vancouver Island (Ford et al. 2000). J pod differs considerably in its movements during this time and is present only intermittently in the Georgia Basin and Puget Sound.

While in inland waters during warmer months, all of the pods concentrate their activity in Haro Strait, Boundary Passage, the southern Gulf Islands, the eastern end of the Strait of Juan de Fuca, and several localities in the southern Georgia Strait (Figure 6; Heimlich-Boran 1988, Felleman et al. 1991, Olson 1998, Ford et al. 2000). Less time is generally spent elsewhere, including other sections of the Georgia Strait, Strait of Juan de Fuca, and San Juan Islands, Admiralty Inlet west of Whidbey Island, and Puget Sound. Individual pods are generally similar in their preferred areas of use (Olson 1998), although some seasonal and temporal differences exist in areas visited (Hauser, unpubl. data). For example, J pod is the only group to venture regularly inside the San Juan Islands (K. C. Balcomb, unpubl. data). Pods commonly seek out and forage in areas that salmon most commonly occur, especially those associated with migrating salmon (Heimlich-Boran 1986a, 1988, Nichol and Shackleton 1996). Notable locations of particularly high use include Haro Strait and Boundary Passage, the southern tip of Vancouver Island, Swanson



Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1976	■	■	■	J,K	□	▒	▒	▒	▒	▒	■	□
1977	■	■	■	■	■	■	▒	▒	▒	▒	▒	▒
1978	□	□	J,K	□	□	□	▒	▒	▒	▒	□	□
1979	□	□	□	□	□	▒	▒	▒	▒	▒	J,K	□
1980	□	□	□	□	□	▒	▒	▒	▒	▒	□	□
1981	□	□	□	J,K	□	▒	▒	▒	▒	▒	▒	□
1982	□	□	□	□	□	J,K	▒	▒	▒	J,K	□	□
1983	□	□	□	□	□	▒	▒	▒	▒	J,K	J,K	□
1984	□	□	□	□	□	J,K	▒	▒	▒	□	□	□
1985	□	□	□	□	□	J,K	▒	▒	▒	▒	□	□
1986	□	□	□	□	J,K	▒	▒	▒	▒	□	□	□
1987	□	□	□	□	□	▒	▒	▒	▒	J,K	J,K	J,K
1988	□	□	□	□	J,K	▒	▒	▒	▒	▒	□	□
1989	□	□	J,K	□	▒	▒	▒	▒	▒	J,K	J,K	J,K
1990	□	□	□	□	▒	▒	▒	▒	▒	▒	□	□
1991	□	□	□	□	J,K	▒	▒	▒	▒	J,K	□	□
1992	□	□	□	□	▒	▒	▒	▒	▒	▒	▒	▒
1993	□	□	□	□	J,K	▒	▒	▒	▒	□	□	□
1994	□	□	□	□	□	▒	▒	▒	▒	J,L	□	□
1995	□	□	□	□	▒	▒	▒	▒	▒	□	□	□
1996	□	□	□	□	□	▒	▒	▒	▒	J,K	J,K	□
1997	□	□	□	□	□	▒	▒	▒	▒	J,L	J,L	□
1998	□	□	□	□	▒	▒	▒	▒	▒	▒	J,K	□
1999	□	□	□	□	□	▒	▒	▒	▒	▒	▒	▒
2000	▒	□	□	□	□	▒	▒	▒	▒	▒	▒	▒
2001	▒	▒	□	□	▒	▒	▒	▒	▒	▒	▒	▒
2002	▒	▒	□	□	▒	▒	▒	▒	▒	▒	▒	▒
2003	▒	▒	□	□	□	▒	▒	▒	▒	▒	▒	J,K
2004	▒	□	□	□	J,L	J,L	▒	▒	▒	▒	▒	J,K

Only J Pod present	□	Two pods present, as indicated	░	J, K, and L pods present	▒	Data not available	■

Figure 5. Monthly occurrence of the three southern resident killer whale pods (J, K, and L) in the inland waters of Washington and British Columbia, 1976-2004. This geographic area is defined as the region east of Race Rocks at the southern end of Vancouver Island and Port Angeles on the Olympic Peninsula. Data come from a historical sighting archive held at The Whale Museum (2004).

Channel off North Pender Island, and the mouth of the Fraser River delta, which is visited by all three pods in September and October (Figure 6; Felleman et al. 1991; Ford et al. 2000; K. C. Balcomb, unpubl. data). These sites are major corridors of migrating salmon.

During early autumn, southern resident pods, especially J pod, expand their routine movements into Puget Sound to likely take advantage of chum and chinook salmon runs (Osborne 1999). In recent years, this has become the only time of year that K and L pods regularly occur in the sound. Movements into seldom-visited bodies of water may occur at this time. One noteworthy example of such use occurred in Dyes Inlet near Bremerton in 1997. Nineteen members of L

Figure 6. Primary area of occurrence (light shading) of southern resident killer whales (J, K, and L pods) when present in the Georgia Basin and Puget Sound. Adapted from Heimlich-Boran (1988), Olson (1998), and Ford et al. (2000), with additional information from D. K. Ellifrit (pers. comm.).

pod entered the 19-km^2-sized inlet, which is surrounded by urban and residential development, on 21 October during a strong run of chum salmon into Chico Creek and remained there until 19 November, when salmon abundance finally tapered off. The reasons for this long length of residence are unclear, but may have been related to food abundance (K. C. Balcomb, pers. comm.; D. K. Ellifrit, pers. comm.) or a reluctance by the whales to depart the inlet because of the physical presence of a bridge crossing the Port Washington Narrows and associated road noise (J. Smith, pers. comm.).

Late spring to early fall movements of southern residents in the Georgia Basin have remained fairly consistent since the early 1970s, with strong site fidelity shown to the region as a whole. However, some areas of use have changed over time. Visitation of Puget Sound has diminished since the mid-1980s, whereas Swanson Channel receives noticeably more use now than in the past (K. C. Balcomb, unpubl. data). Long-term differences in the availability of salmon at particular sites are one possible explanation for these alterations. Another cause may be the deaths of certain older experienced whales that were knowledgeable of good feeding sites, but who are no longer present to direct the movements of their pods to these sites or along favored travel routes.

During the late fall, winter, and early spring, the ranges and movements of the southern residents are much more poorly known. J pod continues to occur intermittently in the Georgia Basin and Puget Sound throughout this time (Figure 5), but its location during apparent absences is uncertain (Osborne 1999). One sighting of this pod was made off Cape Flattery, Washington, in March 2004 (Krahn et al. 2004a). Prior to 1999, K and L pods followed a general pattern in which they spent progressively smaller amounts of time in inland waters during October and November and departed them entirely by December of most years (Figure 5; Osborne 1999). Sightings of both groups passing through the Strait of Juan de Fuca in late fall suggested that activity shifted to the outer coasts of Vancouver Island and Washington, although it was unclear if the whales spent a substantial portion of their time in this area or were simply in transit to other locations (Krahn et al. 2002). Since the winter of 1999-2000, K and L pods have extended their use of inland waters until January or February each year (Figure 5). The causes behind this change are unknown, but may relate to altered food availability, for example, increased abundance of chum or hatchery chinook in these waters or reduced food resources along the outer coast (R. W. Osborne, pers. comm.). Thus, since 1999, both pods are completely absent from the Georgia Basin and Puget Sound only from about early or mid-February to May or June.

Areas of activity by K and L pods are virtually unknown during their absences. Only 22 verified sightings of one or both pods have occurred along the outer coast from 1975-2004, with most made from January to May (Krahn et al. 2004a). These include 13 records off Vancouver Island, six off Washington, three off Oregon, and two off Monterey Bay, California. There have also been several observations of resident whales that were most likely these pods near the Columbia River mouth during April in recent years (K. C. Balcomb, unpubl. data). Most records have occurred since 1996, but this is perhaps more likely due to increased viewing effort along the coast rather than a recent change in the pattern of occurrence for this time of year. The southern residents were formerly thought to range southward along the coast only to about Grays Harbor (Bigg et al. 1990) or the mouth of the Columbia River (Ford et al. 2000). However, recent sightings of members of K and L pods in Oregon (L pod at Depoe Bay in April 1999 and Yaquina Bay in March 2000, and unidentified southern residents at Depoe Bay in April 2000) and California (17 members of L pod and four members of K pod at Monterey Bay on 29 January 2000, and L71 and probably other L pod members at the same site on 13 March 2003) have considerably extended the southern limit of their known range (Black et al. 2001, Monterey Bay Whale Watch 2003, Krahn et al. 2004a). Both Monterey sightings coincided with large runs of chinook salmon, with feeding on chinook witnessed in 2000 (K. C. Balcomb, unpubl. data). L pod was also seen feeding on unidentified salmon off Westport, Washington, in March 2004 during the spring chinook run in the Columbia River (M. B. Hanson, pers. obs., in Krahn et al. 2004a).

Available information suggests that K and L pods travel to northern Vancouver Island and occasionally to the Queen Charlotte Islands during May and June. Multiple sightings have been made during this period near Tofino on the west-central coast of Vancouver Island (Krahn et al. 2004a). Both pods sometimes make their initial spring entry into the Strait of Georgia via Johnstone Strait (Ford et al. 2000), implying regular movement around the northern end of Vancouver Island. On 28 May 2003, members of both pods were identified for the first time in the Queen Charlottes, when a group of 30 or more whales was viewed off Langara Island (54°15'N, 133°02'W) at the north end of the island group about 46 km south of Alaska (J. K. B. Ford and G. M. Ellis, unpubl. data). Other records from this region include the carcass of an unidentified southern resident (recognized through genetic testing) that was found on the west coast of the Queen Charlottes in June 1995 (Ford et al. 2000) and another dead individual found off Cape Scott at the northwestern tip of Vancouver Island in May 1996 (J. K. B. Ford, pers. comm.).

Due to extensive changes in many salmon stocks along the North American west coast during the past 150 years, it is possible that the current movement patterns of the southern residents are somewhat different from those of several centuries ago. In particular, the whales may have once been regularly attracted to the Columbia River mouth, where immense numbers of salmon previously returned during their spawning migrations (K. C. Balcomb, pers. comm.). Morin et al. (2004) has recently attempted to assess the extent of past movements of these whales to California by examining mitochondrial DNA from specimens collected there from the mid-1800s to 1979. No southern residents were found in the sample (i.e., only transient and offshore haplotypes were detected). Although this outcome is not conclusive proof that southern residents did not historically visit Californian waters, it does suggest that such movements may have been infrequent or highly seasonal during the past 150 years.

Northern residents. Despite considerable overlap in their full geographic distributions (Figure 3), southern and northern residents maintain separate ranges during most of the year. Some northern resident pods are seen most predictably from June to October in western Johnstone Strait and Queen Charlotte Strait, where occurrence is closely associated with salmon congregating to enter spawning rivers (Morton 1990, Nichol and Shackleton 1996, Ford et al. 2000). However, the majority of animals occur farther north during this season in passages and inlets of the central and northern British Columbia coast, in Hecate Strait and Queen Charlotte Islands, and reaching Frederick Sound in southeastern Alaska (Nichol and Shackleton 1996, Dahlheim et al. 1997, Ford et al. 2000). Less information is available on the winter distribution of northern residents, but use of Johnstone Strait and neighboring areas declines markedly during this time (Morton 1990, Nichol and Shackleton 1996). The two communities occur sympatrically at times during the spring, when some southern residents visit northern Vancouver Island and the Queen Charlotte Islands (Osborne 1999, Ford et al. 2000). Northern resident pods have been rarely documented in Washington State at locations as far south as the eastern Strait of Juan de Fuca and off Grays Harbor (Calambokidis et al. 2004, Wiles 2004; D. K. Ellifrit, unpubl. data; J. K. B. Ford, unpubl. data).

West coast transients. This is the only transient community that overlaps in range with the southern residents, being distributed from the Los Angeles area of southern California to the Icy

Strait and Glacier Bay region of southeastern Alaska (Figure 4; Ford and Ellis 1999, Baird 2001, Barrett-Lennard and Ellis 2001; N. A. Black, pers. comm.). Transient whales are considered farther ranging and more unpredictable in their daily movements than residents, but detailed information on seasonal movements is not available because of the relatively few identifications made of nearly all individuals. In contrast to the southern residents, transient patterns of occurrence show less seasonal change in abundance and distribution, which probably relates to the year-round presence of their marine mammal prey (Ford and Ellis 1999). Photo-identification records indicate some transients are regularly seen in particular sub-regions (e.g., moderately sized areas of British Columbia and southeastern Alaska), suggesting that they inhabit preferred seasonal or annual home ranges, whereas other individuals travel across much of the community's geographic range (Ford and Ellis 1999). Regional-scale movements are evident in many of the transients identified in British Columbia or Washington, with slightly more than half (111 of 206 animals) having been sighted in southeastern Alaska (Dahlheim et al. 1997, Ford and Ellis 1999). About 13% of the individuals photographed off California have been observed in Washington, British Columbia, or Alaska (Black et al. 1997). Most transient sightings in Washington and around Vancouver Island occur in the summer and early fall, when viewing effort is greatest and harbor seals pup (Morton 1990, Baird and Dill 1995, Olson 1998, Ford and Ellis 1999). Observations in the Georgia Basin and Puget Sound are concentrated around southeastern Vancouver Island, the San Juan Islands, and the southern edge of the Gulf Islands (Olson 1998; K. C. Balcomb, unpubl. data). Additional information on the movements of this community is summarized in Ford and Ellis (1999) and Wiles (2004).

Offshores. The offshore community is distributed from the area north of Los Angeles in southern California to the eastern Aleutian Islands (Ford and Ellis 1999; M. E. Dahlheim, unpubl. data; N. A. Black, pers. comm.), giving it the largest geographic range of any killer whale community in the northeastern Pacific. However, movements of individual animals are poorly understood due to the small numbers of verified observations. At least 20 of the approximately 200 individuals photographed in Washington, British Columbia, and Alaska have been sighted in California (Black et al. 1997; M. E. Dahlheim, unpubl. data), indicating that extensive movements may be normal in some animals. Such travel patterns may be related to the movements of migratory fish that are possibly eaten (Krahn et al. 2004a). Offshore killer whales primarily inhabit offshore locations, but are also seen in nearshore coastal waters and occasionally in inland waters (see summary in Wiles 2004).

Dispersal among residents and transients. Social dispersal, in which an animal more-or-less permanently departs its natal group to live alone or in association with unrelated individuals while remaining part of the breeding population, has never been recorded in resident killer whales, which maintain highly stable social bonds throughout their lives (Bigg et al. 1990, Baird 2000, Ford et al. 2000). By comparison, such dispersal is believed to occur commonly in transient whales, with juveniles and adults of both sexes participating (Ford and Ellis 1999, Baird 2000, Baird and Whitehead 2000). In doing so, dispersing transients continue to occupy their large natal geographic ranges throughout their lives.

Several instances of young solitary resident killer whales found away from their natal pods have been recorded in Washington and British Columbia (Balcomb 2002), but likely represent orphaned or poorly nurtured individuals that became separated from their pods rather than true examples of dispersal. Animals such as these are believed to usually die rather than reestablish permanent bonds with other resident whales. A73, a one-year old northern resident female, appeared in Puget Sound in late 2001 or early 2002 far from its expected range and eventually took up residence near Seattle. It remained there until being captured in June 2002, after which it was translocated back to its natal pod in Johnstone Strait. This individual suffered from declining health prior to its capture and would have likely died without human intervention. L98, a southern resident male, was discovered in Nootka Sound on western Vancouver Island in July 2001 after apparently becoming separated from L pod at about 2 years of age and has since resided alone there. It has remained healthy throughout this time, but is more threatened by interactions with humans.

Habitat Use

Killer whales frequent a variety of marine habitats with adequate prey resources and do not appear to be constrained by water depth, temperature, or salinity (Baird 2000). Although the species occurs widely as a pelagic inhabitant of open ocean, many populations spend large amounts of time in shallower coastal and inland marine waters, foraging even in inter-tidal areas in just a few meters of water. Killer whales tolerate a range of water temperatures, occurring from warm tropical seas to polar regions with ice floes and near-freezing waters. Brackish waters and rivers are also occasionally entered (Scheffer and Slipp 1948, Tomilin 1957). Individual knowledge of productive feeding areas and other special habitats (e.g., beach rubbing sites) is probably an important determinant in the selection of locations visited and is likely a learned tradition passed from one generation to the next (Ford et al. 1998).

Residents. Resident and transient killer whales exhibit somewhat different patterns of habitat use while in protected inland waters, where most observations are made (Heimlich-Boran 1988, Morton 1990, Felleman et al. 1991, Baird and Dill 1995, Matkin and Saulitis 1997, Scheel et al. 2001). Residents generally spend more time in deeper water and only occasionally enter water less than 5 m deep (Heimlich-Boran 1988, Baird 2000, 2001). Distribution is strongly associated with areas of greater salmon abundance (Heimlich-Boran 1986a, 1988, Felleman et al. 1991, Nichol and Shackleton 1996), but research to date has yielded conflicting information on preferred foraging habitats. Several studies have reported that southern residents feed heavily in areas characterized by high-relief underwater topography, such as subsurface canyons, seamounts, ridges, and steep slopes (Heimlich-Boran 1988, Felleman et al. 1991). Such features may limit fish movements, thereby resulting in greater prey availability, and be used by the whales as underwater barriers to assist in herding fish (Heimlich-Boran 1988). The primary prey at greater depths may be chinook salmon, which swim at depths averaging 25-80 m and extending down to 300-400 m (Candy and Quinn 1999). Other salmonids mostly inhabit the upper 30 m of the water column (Quinn and terHart 1987, Quinn et al. 1989, Ruggerone et al. 1990, Ishida et al. 2001).

In contrast, Hoelzel (1993) reported no correlation between the feeding behavior of residents and bottom topography, and found that most foraging took place over deep open water (41% of sightings), shallow slopes (32%), and deep slopes (19%). Ford et al. (1998) described residents as frequently foraging within 50-100 m of shore and using steep nearshore topography to corral fish. Both of these studies, plus those of Baird et al. (2003, in prep.), have reported that most feeding and diving activity occurs in the upper 30 m of the water column, where most salmon are distributed (Stasko et al. 1976, Quinn and terHart 1987, Quinn et al. 1989, Ruggerone et al. 1990, Olson and Quinn 1993, Nichol and Shackleton 1996, Candy and Quinn 1999, Baird 2000). Additionally, chinook salmon occupy nearshore habitats more so than other salmonids (Stasko et al. 1976, Quinn et al. 1989). Reasons for the discrepancies between studies are unclear, but may result from interpod variation and differences in study methodology (Nichol and Shackleton 1996, Baird 2001). Baird et al. (in prep.) have recently reported a shift to shallower daytime depths among southern residents between 1993 and 2002, which possibly reflects long-term changes in prey behavior or selection of prey.

Other behaviors, such as resting and socializing, are performed in open water with varied bathymetry (Heimlich-Boran 1988, Felleman et al. 1991). Habitat use patterns are poorly understood for southern resident pods visiting the outer coast.

Transients. Transient whales also occupy a wide range of water depths, including deep areas exceeding 300 m. However, transients show greater variability in habitat use than residents, with some groups spending most of their time foraging in shallow waters close to shore and others hunting almost entirely in open water (Heimlich-Boran 1988, Felleman et al. 1991, Baird and Dill 1995, Matkin and Saulitis 1997). Small bays and narrow passages are entered, in contrast to residents (Morton 1990, Scheel et al. 2001). Groups using nearshore habitats often concentrate their activity in shallow waters near pinniped haul-out sites. While foraging, these whales often closely follow the shoreline, entering small bays and narrow passages, circling small islets and rocks, and exploring inter-tidal areas at high tides. Transients that spend more time in open water probably prey more frequently on porpoises as well as pinnipeds.

Occurrence along outer coastlines. Abundance patterns of killer whales are poorly known for many outer coastal areas of western North America. Several studies off Washington and Oregon have reported relatively low encounter rates during shipborne and aerial surveys, with most sightings made along the continental shelf within about 50 km of land (Green et al. 1992, 1993, Shelden et al. 2000). Very few observations during these studies were identifiable to community type. Killer whales were encountered somewhat more often during another study by Calambokidis et al. (2004), who conducted summer ship surveys off the Olympic Peninsula from 1995-2002. These researchers detected transient whales most frequently, but members of the southern and northern resident and offshore communities were also observed. Sightings were made predominantly at mid-shelf depths averaging 100-200 m and at distances of 40-80 km from land. Killer whales were also regularly observed during another series of shipboard transects conducted off California, Oregon, and Washington from 1991-2001, although community type was again not determined (Barlow 2003, Carretta et al. 2004).

Use of rivers. Killer whales in the northeastern Pacific occasionally enter the lower reaches of rivers while foraging. Use of the lower Fraser River by resident killer whales has been reported (Baird 2001, pers. comm.) and may have involved animals in pursuit of salmon. Transients have been recently recorded in several rivers or river mouths in Oregon (K. C. Balcomb, unpubl.

data). Several instances of whales ascending up to 180 km up the Columbia River are known from the 1930s and 1940s (Shepard 1932, Scheffer and Slipp 1948), but it is not known whether these animals were resident or transient whales.

Reproduction and Growth

Much of the information on reproduction and growth in killer whales comes either from observations of animals held in captivity or from long-term photo-identification studies of the resident whale communities in Washington and British Columbia (Olesiuk et al. 1990a). Variation in these parameters can be expected in other populations (Ford 2002).

Mating system. Killer whales are polygamous (Dahlheim and Heyning 1999). Recent paternity analyses using microsatellite DNA indicate that resident males nearly always mate with females outside of their own pods, thereby reducing the risks of inbreeding (Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001). Differences in dialects very likely assist animals in determining the degree of relatedness among prospective mating partners, with female choice probably being the major factor in the mating success of males (Ford 1989, 1991, Ford et al. 2000, Yurk et al. 2002).

Mating season and estrous activity. Most mating in the North Pacific is believed to occur from May to October (Nishiwaki 1972, Olesiuk et al. 1990a, Matkin et al. 1997). However, small numbers of conceptions apparently happen year-round, as evidenced by births of calves in all months.

Captive adult females experience periods of multiple estrous cycling interspersed with intervals of non-cycling (Walker et al. 1988, Robeck et al. 1993, Duffield et al. 1995). The lengths of these periods are highly variable, both within an individual and a population. Estrous cycle lengths average 42-44 days (range = 18-91 days), with a mean of four cycles (range = 1-12 cycles) during polyestrous. Non-cycling intervals last an average of 7-8 months (range = 3-16 months) (Robeck et al. 1993, Duffield et al. 1995). Profiles of reproductive hormones during ovarian cycles and pregnancy in captive females are presented by Walker et al. (1988) and Duffield et al. (1995).

Calving interval. Estimates of calving intervals, defined as the length of time between the births of surviving calves, average from 4.9 to 7.7 years (range = 2-14 years) in the northeastern Pacific (Olesiuk et al. 1990a, Krahn et al. 2002, 2004a, Matkin et al. 2003) and range from 3.0-8.3 years in the North Atlantic and Antarctica (Christensen 1984, Perrin and Reilly 1984). Females in captivity have produced calves 2.7-4.8 years apart (Duffield et al. 1995), while Hoyt (1990) cited a captive female that gave birth 19 months after the death of her previous newborn calf. Jacobsen (1986) observed copulation in a wild female that had given birth to and then lost a calf the previous year. Several authors have suggested that birth rates in some populations may be density dependent (Fowler 1984, Kasuya and Marsh 1984, Brault and Caswell 1993, Dahlheim and Heyning 1999). However, no study has confirmed this trait among resident whales in the northeastern Pacific (Olesiuk et al. 1990a, Taylor and Plater 2001). Olesiuk et al. (1990a) reported mean annual pregnancy rates of 52.8% for resident females of reproductive age and 35.4% for all mature resident females in Washington and British Columbia.

Gestation period. Gestation periods in captive killer whales average about 17 months (mean ± SD = 517 ± 20 days, range = 468-539 days) (Asper et al. 1988, Walker et al. 1988, Duffield et al. 1995). Fetal development and morphology have been described in several studies (Turner 1872, Guldberg and Nansen 1894, Benirschke and Cornell 1987).

Calving season and characteristics of newborns. Among resident killer whales in the northeastern Pacific, births occur largely from October to March, but may take place during any month (Olesiuk et al. 1990a). Parturition dates are thought to be mainly from November to February in the North Atlantic (Jonsgård and Lyshoel 1970, Evans 1988) and from January to April in the Antarctic, which corresponds there to the late austral summer (Anderson 1982). Only single calves are born. Several previous reports of twins (e.g., Olesiuk et al. 1990a, Baird 2000) have proven erroneous (Ford and Ellis 1999). Nearly all calves are born tail-first (Duffield et al. 1995). Newborns measure 2.2-2.7 m long and weigh about 200 kg (Nishiwaki and Handa 1958, Olesiuk et al. 1990a, Clark et al. 2000, Ford 2002). Heyning (1988) reported a mean length of 2.36 m in northeastern Pacific calves. Sex ratios at birth are probably 1:1 (Dahlheim and Heyning 1999). Taylor and Plater (2001) reported a sex ratio of 57% males among 65 southern resident calves born after 1973, but this did not differ significantly from a 1:1 sex ratio.

Development and growth of young. Calves remain close to their mothers during their first year of life, often swimming slightly behind and to the side of the mother's dorsal fin. Weaning age remains unknown, but nursing probably ends at 1-2 years of age (Haenel 1986, Kastelein et al. 2003). Tooth eruption begins from several to 11 weeks of age, which is about the time that calves begin taking solid food from their mothers (Haenel 1986, Asper et al. 1988, Heyning 1988, Kastelein et al. 2003). Asper et al. (1988) reported a captive calf that consumed 6.6 kg of fish per day at 5 months of age and 22 kg per day of fish and squid at 15 months of age. Another captive animal increased its food consumption from about 22 kg per day at one year of age to about 45 kg at 10 years of age (Kastelein and Vaughan 1989). As young killer whales grow older, they spend increasing amounts of time with siblings and other pod members (Haenel 1986). Juveniles are especially active and curious. They regularly join subgroups of several other youngsters and participate in chasing, leaping, and high-speed porpoising. Young males of 2-6 years of age also engage in displays of sexual behavior. Among resident whales, maternal associations slowly weaken as juveniles reach adolescence (Haenel 1986), but typically continue well into adulthood.

Studies to date have yielded somewhat contradictory information on growth patterns of killer whales, which may partially reflect population differences and whether or not the animals were wild or captive. Christensen (1984) indicated that males and females displayed similar growth rates up to about 15 years of age, but Clark et al. (2000) found that males had lower growth rates than females during the ages of one to six. Several studies have reported linear growth rates during the first nine to 12 years for females and first 12 to 16 years in males, after which growth slows in both sexes (Bigg 1982, Duffield and Miller 1988). Annual growth rates for captive juveniles originating from the northeastern Pacific averaged 38 cm per year (range = 26-52 cm per year), but fell into two categories for animals from the North Atlantic, averaging 21 cm per year (range = 17-25 cm per year) in one group and 39 cm per year (range = 31-48 cm per year) in a second group (Duffield and Miller 1988). For youngsters one to six years of age, Clark et al. (2000) reported mean growth rates of 28 cm and 182 kg per year for males and 36 cm and 248 kg per year for females. Based on whaling data, Christensen (1984) suggested that male killer whales enter a period of sudden growth during adolescence. The validity of this finding has been questioned (Duffield and Miller 1988, Baird 2000), but measurements taken by Clark and Odell (1999) support Christensen's (1984) hypothesis. Both sexes continue to grow until physical maturity is reached at about 19-25 years of age (Olesiuk et al. 1990a, Christensen 1984, Kastelein et al. 2000). Bigg and Wolman (1975) calculated the relationship between body length and weight in both sexes of killer whale as being: weight = 0.000208 length$^{2.577}$ (weight in kg, length in cm). Kastelein et al. (2003) noted a similar growth pattern among captive animals.

Characteristics of reproductive adults. Females achieve sexual maturity at lengths of 4.6-5.4 m, depending on geographical region (Perrin and Reilly 1984). Wild females from the northeastern Pacific give birth to their first surviving calf between the ages of 12 and 16 years (mean = about 14.9 years) (Olesiuk et al. 1990a, Matkin et al. 2003), but when adjusted for the high mortality rate among newborns, the probable mean age at first birth of either a viable or non-viable calf is reduced to 13.1 years (Olesiuk et al. 1990a). This latter age corresponds to a probable mean age at first conception of 11.7 years. Pubescent females may ovulate several times before conceiving, thus average age at first ovulation is probably even younger (Olesiuk et al. 1990a). Duffield et al. (1995) reported similar ages for initial births among captive females from this region, but noted a captive-born female that gave birth when 8 years old. Somewhat younger ages of 7-14 years have been reported for North Atlantic females becoming sexually mature or bearing their first calf (Christensen 1984, Duffield et al. 1995, Kastelein et al. 2003). Females produce an average of 5.4 surviving calves during a reproductive life span lasting about 25 years (Olesiuk et al. 1990a). Breeding ends at about 40 years of age. Females then enter a post-reproductive period that continues until their death. This averages about 10 years in length, but extends more than 30 years in a few individuals. Males become sexually mature at body lengths ranging from 5.2-6.4 m, which corresponds to ages of 10 to 17.5 years (mean = about 15 years) (Christensen 1984, Perrin and Reilly 1984, Duffield and Miller 1988, Olesiuk et al. 1990a). Males are presumed to remain sexually active throughout their adult lives (see Olesiuk et al. 1990a).

Survival, Longevity, and Natural Mortality

Survival. Population demography in the species is best understood for the southern and northern resident communities. The detailed information presented by Olesiuk et al. (1990a) was gathered when both populations were generally expanding in size. However, Krahn et al.'s (2002, 2004a) recent investigations of the southern resident population, which included data from the most recent decline, demonstrate that some of these parameters are no longer accurate. Mortality curves are U-shaped for both sexes, although the curve is narrower for males (Olesiuk et al. 1990a). Mortality is extremely high during the first six months of life, when 37-50% of all calves die (Bain 1990, Olesiuk et al. 1990a). Annual death rates for juveniles decline steadily thereafter, falling to 0.5% for both sexes from 10.5 to 14.5 years of age, and an estimated 77% of viable calves reach adulthood. Death rates remain low among females of reproductive age, averaging just 0-1.7% per year between 15.5 and 44.5 years (Olesiuk et al. 1990a). Mortality increases dramatically among older females, especially those beyond 65 years of age. After reaching sexual maturity, death rates for males increase throughout life, reaching 7.1% annually among individuals older than 30 years. Life history tables for both of these resident populations are presented in Olesiuk et al. (1990a). Fairly similar survival patterns have been reported among the southern Alaska residents (Matkin et al. 2003).

Seasonal mortality rates among southern and northern resident whales have not been analyzed, but are believed to be highest during the winter and early spring, based on the numbers of animals missing from pods returning to inland waters each spring (J. K. B. Ford, pers. comm.; K. C. Balcomb, pers. comm.). This contention is supported by the somewhat higher spring stranding rates among all killer whale forms in Washington and Oregon (Norman et al. 2004).

Comparable data for transients and offshores are not available because of the difficulty in closely monitoring their populations, but death rates in transients are perhaps similar to those of residents (Ford and Ellis 1999). Killer whales held in captivity suffer considerably higher overall rates of mortality of 6.2-8.9% per year (DeMaster and Drevenak 1988, Duffield and Miller 1988, Small and DeMaster 1995).

Longevity. At birth, the average life expectancy of southern and northern resident killer whales is about 29 years for females and 17 years for males (Olesiuk et al. 1990a). However, for animals that survive their first six months, mean life expectancy increases to about 50-60 years for females and 29 years for males. Life expectancy at sexual maturity (about 15 years of age in both sexes) averages about 63 years for females and 36 years for males. Maximum life span is estimated to be 80-90 years for females and 50-60 years for males (Olesiuk et al. 1990a). Reasons for the shorter longevity of males are unknown, but are probably linked to sexual selection (Baird 2000). Among southern Alaska residents, females reaching 6 months of age have a shorter life expectancy of 39 years and a maximum life span of 60-70 years (Matkin et al. 2003).

Natural mortality. Natural causes of death in killer whales remain largely unidentified, even in the well-investigated southern and northern resident populations. Animals usually sink after dying, giving researchers little opportunity to conduct post-mortem examinations of carcasses. Thus, reasons for the high mortality rates among calves are not known (Baird 2000). Killer whales have no predators other than humans (Baird 2000, Ford 2002). Field observations and the lack of shark-induced scars, such as those seen on some dolphin species (Corkeron et al. 1987, Heithaus 2001), suggest that shark predation is insignificant even on young animals (Baird 2000). Visible signs of emaciation are rarely seen among resident and transient whales in Washington and British Columbia (K. C. Balcomb, pers. comm.; J. K. B. Ford, pers. comm.; R. W. Baird, pers. comm.), thus it is unknown whether these populations experience annual periods of food scarcity that might contribute to increased mortality.

Individual and mass live strandings and entrapments of killer whales are considered rare (Dahlheim and Heyning 1999) and often end in the deaths of some or most animals. These events sometimes result when whales foraging in shallow waters become accidentally trapped by a receding tide, but fast-forming ice can also be a cause (Taylor 1957, Mitchell and Reeves 1988, Reeves et al. 2002). Disease, parasitism, and intense human-generated sound may also drive animals ashore in some cases (Walsh et al. 2001, Perrin and Geraci 2002). Fewer than 20 records of mass strandings are known worldwide, but four of these occurred in British Columbia during the 1940s (Pike and MacAskie 1969, Mitchell and Reeves 1988; M. Sternfeld, unpubl. data). These included 11 whales stranded near Masset in the Queen Charlotte Islands in January 1941 (Cameron 1941), "a number" of whales temporarily stranded at Cherry Point near Cowichan Bay, Vancouver Island, in September 1944 (Carl 1946), and 20 whales stranded near Estevan Point on western Vancouver Island in June 1945 (Carl 1946). Pike and MacAskie (1969) described five entrapped whales that eventually stranded and died in Von Donnop Lagoon on Cortez Island near Campbell River, Vancouver Island, in March 1949. Seven strandings or entrapments involving three or more whales have occurred in Alaska since 1982 (Lowry et al. 1987, Heise et al. 2003, Shelden et al. 2003; M. B. Hanson, unpubl. data; M. Sternfeld, unpubl. data) and are the only other records reported from western North America (Mitchell and Reeves 1988, Norman et al. 2004; J. Gaydos, unpubl. data; N. A. Black, pers. comm.). These involved a mean of 5.6 animals, with the largest event comprised of nine offshore whales trapped in Barnes Lake on Prince of Wales Island for about two months in 1994 (D. E. Bain, unpubl. data). Two of the animals died before the remainder were driven back to the ocean by rescuers.

In recent years in Washington, live strandings of one or two individuals have included a 2.8-m female presumed to be a southern resident at Port Madison in August 1970, a 4.8-m female also presumed to be a southern resident at Ocean City in March 1973, and two adult transients (one was rescued) at Dungeness Spit in January 2002. Several older stranding records are also known from the state (Scheffer and Slipp 1948). Scheffer and Slipp (1948) described two entrapments involving single whales in Puget Sound, including one animal caught behind a dock. Both escaped on the next tide.

Diseases. Causes of death have been reported for killer whales held in captivity, but may not be representative of mortality in the wild. Deaths of 32 captive individuals were attributed to pneumonia (25%), systemic mycosis (22%), other bacterial infections (16%), mediastinal abscesses (9%), and undiagnosed causes (28%) (Greenwood and Taylor 1985). Little is known about infectious diseases of wild killer whales or the threat that they pose to populations. Sixteen pathogens have been identified from captive and free-ranging animals, including nine types of bacteria, four viruses, and three fungi (Gaydos et al. 2004). Three of these, marine *Brucella*, *Edwardsiella tarda*, and cetacean poxvirus, were detected in wild individuals. Marine *Brucella* and cetacean poxvirus have the potential to cause mortality in calves and marine *Brucella* may cause abortion (Miller et al. 1999, Van Bressem et al. 1999). Cetacean poxvirus also produces skin lesions, but probably does not cause many deaths in cetaceans (Van Bressem et al. 1999). Antibodies to *Brucella* spp. were detected in a female transient that stranded at Dungeness Spit in January 2002 (Gaydos et al. 2004). In 2000, a male southern resident died from a severe infection caused by *E. tarda* (Ford et al. 2000). Gaydos et al. (2004) identified an additional 27 pathogens (12 fungi, 11 bacteria, and four viruses) from other species of toothed whales that are sympatric with the southern residents and considered these as potentially transmittable to killer whales. Several, including porpoise morbillivirus, dolphin morbillivirus, and herpesviruses, are highly virulent and are capable of causing large-scale disease outbreaks in some related species. Disease epidemics have never been reported in killer whales in the northeastern Pacific (Gaydos et al. 2004).

Killer whales are susceptible to other forms of disease, including Hodgkin's disease and severe atherosclerosis of the coronary arteries (Roberts et al. 1965, Yonezawa et al. 1989). Tumors and bone fusion have also been recorded (Tomilin 1957). Jaw abscesses and dental disease are common problems caused by heavy tooth wear down to the gum line, resulting in exposure and infection of the pulp cavity and surrounding tissue (Carl 1946, Tomilin 1957, Caldwell and Brown 1964). Noticeable tooth wear can occur even in some younger animals (Carl 1946). Captive animals commonly suffer from abscessed vestigial hair follicles on the rostrum, a condition that can eventually spread over the entire skin surface (Simpson and Gardner 1972). A genetic disorder known as Chediak-Higashi syndrome was diagnosed in a young transient killer whale from southern Vancouver Island in the early 1970s (Haley 1973, Taylor and Farrell 1973, Hoyt 1990, Ford and Ellis 1999). The syndrome causes partial albinism, susceptibility to infections, and a reduction in life span.

The collapsed dorsal fins commonly seen in captive killer whales (Hoyt 1992) do not result from a pathogenic condition, but are instead thought to most likely originate from an irreversible structural change in the fin's collagen over time (B. Hanson, pers. comm.). Possible explanations for this include (1) alterations in water balance caused by the stresses of captivity or dietary changes, (2) lowered blood pressure due to reduced activity patterns, or (3) overheating of the collagen brought on by greater exposure of the fin to the ambient air. Collapsed or collapsing dorsal fins are rare in most wild populations (Hoyt 1992, Ford et al. 1994, Visser 1998, Ford and Ellis 1999) and usually result from a serious injury to the fin, such as from being shot or colliding with a vessel. Matkin and Saulitis (1997) reported that the dorsal fins of two male resident whales in Alaska began to fold soon after their pod's exposure to oil during the *Exxon Valdez* spill in 1989 and were completely flattened within two years. Both animals were suspected to be in poor health and subsequently died.

Parasites. Relatively little information is available on the parasites of killer whales. Known endoparasites include *Campula* sp., *Fasciola skrjabini*, *Leucasiella subtilla*, and *Oschmarinella albamarina* (Trematoda), *Diphyllobothrium polyrugosum*, *Phyllobothrium* sp., and *Trigonocotyle spasskyi* (Cestoda), *Anisakis pacificus* and *A. simplex* (Nematoda), *Bolbosoma nipponicum* and *B. physeteris* (Acanthocephala), *Kyaroikeus cetarius* (Ciliata), and *Toxoplasma gondii* (Apicomplexa) (Dailey and Brownell 1972, Heptner et al. 1976, Heyning 1988, Sniezek et al. 1995, Gibson and Bray 1997, Gibson et al. 1998, Murata et al. 2004). These are transmitted primarily through the ingestion of infected prey (Baird 2000). An estimated 5,000 unidentified nematodes were reported in the stomach of a resident whale from Washington (Scheffer and Slipp 1948). The forestomach of a calf estimated at 1-2 months of age in California contained numerous *Anisakis simplex* worms, indicating that infections can begin at an early age (Heyning 1988). Ectoparasites are infrequently found and include the whale lice *Cyamus orcini*, *C. antarcticensis*, and *Isocyamus delphinii* (Amphipoda) (Leung 1970, Berzin and Vlasova 1982, Wardle et al. 2000). Most external parasites are probably transmitted through body contact with other individuals, such as during social encounters and mother-young interactions (Baird 2000). No severe parasitic infestations have been reported in killer whales in the northeastern Pacific.

Commensal organisms associating with killer whales include barnacles, remoras, and diatoms (Hart 1935, Nemoto et al. 1980, Fertl and Landry 1999, Guerrero-Ruiz and Urbán 2000). Barnacles are rare in most populations (Samaras 1989, Dahlheim and Heyning 1999), but are present on many Mexican killer whales (Guerrero-Ruiz 1997, Black et al. 1997).

Human-Related Sources of Mortality and Live-Captures

Aboriginal harvest. The extent that indigenous peoples hunted killer whales in the past is poorly documented. There is no tradition of hunting killer whales in the Canadian Arctic (Reeves and Mitchell 1988b) or along the Pacific coast (Ivashin and Votrogov 1981, Olesiuk et al. 1990a, Matkin et al. 1999a). Hoyt (1990) stated that a general taboo against killing the species was widespread among coastal North American tribes, often based on the fear that surviving whales would avenge the deaths of pod members. Native Alaskans commonly viewed killer whales with respect and considered them as totem (Matkin et al. 1999a). In Washington, the Makah are known to have occasionally caught killer whales and regarded their meat and fat superior to that of baleen whales (Scammon 1874). The species was not hunted by the neighboring Quillayute (Scheffer and Slipp 1948). Carl (1946) reported that the Nootka on Vancouver Island ate the meat and oil from killer whales, but it was unclear whether these were obtained through active hunting or only from beached animals. Small-scale harvesting of killer whales continues to the present at several locations in the world (Reeves et al. 2003).

Commercial exploitation. The first records of commercial hunting of killer whales date back to the 1700s in Japan (Ohsumi 1975). During the 19th and early 20th centuries, the global whaling industry harvested immense numbers of baleen and sperm whales, but largely ignored killer whales because of their limited amounts of recoverable oil, their smaller populations, and the difficulty that whalers had in capturing them (Scammon 1874, Scheffer and Slipp 1948, Budker 1958, Reeves and Mitchell 1988a). No killer whales were reported among the nearly 25,000 whales processed by coastal whaling stations in British Columbia from 1908-1967 (Gregr et al. 2000). Similarly, none were among the 2,698 whales handled at the Bay City whaling plant in Grays Harbor, Washington, during its 14 years of operation from 1911-1925 (Scheffer and Slipp 1948, Crowell 1983).

From the 1920s to 1940s, small whaling fisheries were developed or became more sophisticated in several countries, primarily Norway, the Soviet Union, and Japan, resulting in greater hunting pressure on smaller whales, dolphins, and killer whales (Jonsgård and Lyshoel 1970, Mitchell 1975, Ohsumi 1975, Øien 1988). Available harvest statistics indicate that each of these countries killed an average of about 43-56 killer whales annually from the 1940s to 1981, with most animals taken from the North Atlantic (total = 2,435 whales), Antarctic and southern oceans (1,681 whales), Japanese coastal waters (1,534 whales), and Soviet far east (301 whales) (Ohsumi 1975, Øien 1988, Hoyt 1990). It should be noted that some of the official harvest data from this era are erroneous, with both under-reporting and over-reporting known or suspected to have occurred (Brownell and Yablokov 2002). Furthermore, catch data would likely exclude any wounded animals that escaped and eventually died. These harvests ended by the early 1990s. The only killer whales reported as commercially taken in the northeastern Pacific from the 1940s to early 1980s were a single animal in British Columbia in 1955 (Pike and MacAskie 1969) and five whales in California between 1959 and 1970 (Rice 1974). Although the commercial harvests of this period likely reduced killer whale abundance in some regions of the world, they probably had no impact on most populations in the northeastern Pacific. The current numbers of killer whales hunted for profit in the world are probably quite small (Baird 2001, Reeves et al. 2003), but documentation is lacking. Very small amounts of killer whale meat continued to be present in retail markets in Japan and South Korea during the 1990s, but may have come from animals incidentally caught in coastal fisheries (Baker et al. 2000).

Mortality associated with killer whale depredation. As with other large and highly visible predators, killer whales historically generated a variety of negative emotions among people, ranging from general dislike to fear and outright hatred. Such feelings were most prevalent among fishermen, whalers, sealers, and sportsmen, and largely stemmed from perceived competition over prey resources, damage caused to fishing gear and captured baleen whales, and the belief that killer whales scared off other marine mammals that were potentially harvestable. As a result, killer whales were widely persecuted to varying extents. Shooting was probably the most popular method of responding to nuisance animals (Bennett 1932, Budker 1958, Heptner et al. 1976) and likely resulted in the loss of substantial numbers of whales in some localities so that significant population declines may have occurred (Lien et al. 1988, Olesiuk et al. 1990a). Governments sometimes supported the use of lethal control measures on killer whales, as seen in the opportunistic shooting of animals by fisheries department personnel in British Columbia (Ford et al. 2000, Baird 2001), the establishment of a bounty in Greenland from 1960-1975 (Heide-Jørgensen 1988), the recommendations of Russian scientists to conduct large-scale culling programs to protect seal populations for human harvest (Zenkovich 1938, Tomilin 1957), and the killing of possibly hundreds of whales by the U.S. military in Icelandic waters during the mid-1950s (Anonymous 1954, 1956, Vangstein 1956, Dahlheim 1981, Hoyt 1990) and in the North Atlantic in 1964 (Hoyt 1990).

Animosity toward killer whales has abated in recent decades, but often persists where interference with fishing activities occurs (Klinowska 1991, Matkin and Saulitis 1997). Conflicts with longline fishing operations are common in a number of regions, including Alaska (Rice and Saayman 1987, Matkin 1994, Matkin and Saulitis 1994, Yano and Dahlheim 1995a, 1995b, Ashford et al. 1996, Secchi and Vaske 1998, Visser 2000a, Whale and Dolphin Conservation Society 2002). Longline losses to whales can be extensive and reach 50-100% of the catch in extreme cases. Net fisheries are also affected, including gillnetting and purse seining (Young et al. 1993). As a result, fishermen frequently resort to shooting at killer whales or harassing them with small underwater explosives ("seal bombs") in an effort to drive off the whales (Matkin 1986, 1994, Hoyt 1990, Dahlheim and Matkin 1994, Yano and Dahlheim 1995a, Visser 2000a). Many bullet wounds are probably non-fatal, but accurate information on wounding and killing rates is difficult to obtain.

Deaths from deliberate shooting were probably once relatively common in Washington and British Columbia (Scheffer and Slipp 1948, Pike and MacAskie 1969, Haley 1970, Olesiuk et al. 1990a, Baird 2001). As an indication of the intensity of shooting that occurred until fairly recently, about 25% of the killer whales captured in Puget Sound for aquaria through 1970 bore bullet scars (Hoyt 1990). Shootings have tapered off since then (Hoyt 1990, Olesiuk et al. 1990a, Baird 2001) and only several resident animals currently show evidence of bullet wounds to their dorsal fins (Bigg et al. 1987, Ford et al. 2000). One northern resident, a matriarchal female, died from being shot in 1983 (Ford et al. 2000). Deliberate killings associated with fishery interactions are currently considered insignificant at a population level throughout the northeastern Pacific (Young et al. 1993, Carretta et al. 2001), but may be more prevalent than reported.

Incidental human-related mortality. Drowning from accidental entanglement in nets and longlines is an additional minor source of fishing-related mortality in killer whales. Scheffer and Slipp (1948) documented several deaths of animals caught in gillnets and salmon traps in Washington between 1929 and 1943. Whales are occasionally observed near fishing gear in Washington and British Columbia, and more frequently in much of Alaska, but current evidence indicates that entanglements and deaths are rare except in the Bering Sea (Bigg and Wolman 1975, Barlow et al. 1994, Matkin 1994, Matkin and Saulitis 1994, Pierce et al. 1996, Carretta et al. 2001, 2004; Angliss, in prep.). One individual is known to have contacted a salmon gillnet in British Columbia in 1994, but did not entangle (Guenther et al. 1995). Typically, killer whales are able to avoid nets by swimming around or underneath them (Jacobsen 1986, Matkin 1994). Not all entanglements result in death.

In rare instances, killer whales are injured or killed by collisions with passing ships and powerboats, primarily from being struck by the propeller blades (Visser 1999c, Ford et al. 2000, Visser and Fertl 2000, Baird 2001, Carretta et al. 2001, 2004). Some animals with severe injuries eventually make full recoveries, such as a female described by Ford et al. (2000) that showed healed wounds extending almost to her backbone. Only one mortality from a vessel collision is known to have occurred in Washington and British Columbia during the past 40 years (Baird 2002). Three accidents between vessels and killer whales have been documented in the region since the 1990s (Baird 2001; DFO, unpubl. data). One took place on the Washington side of Haro Strait in 1998 and involved a slow moving boat that apparently did not injure the whale. In 1995, a northern resident was struck by a speedboat, causing a wound to the dorsal fin that quickly healed. Another northern resident was injured by a high-speed boat in 2003, but also recovered.

Major oil spills are potentially catastrophic to killer whales and their environment, as illustrated by the probable impacts on the main resident and transient pods frequenting the area of the massive *Exxon Valdez* oil spill in Prince William Sound, Alaska, which occurred in 1989. Six of the 36 members of AB pod were missing within one week of the spill after being seen in heavily oiled waters and eight more disappeared within two years (Dahlheim and Matkin 1994, Matkin et al. 1994, 1999a, 2003, Matkin and Saulitis 1997). These were followed by the deaths of two orphaned calves in the winter of 1993-1994, as well as two adult males (including one fairly young individual) in 1994 and 1997 whose dorsal fins collapsed soon after the spill, indicating stress or ill health. AT1 pod lost eight of its 22 members by 1990 and two others by 1992. These mortality rates are unprecedented for the northeastern Pacific. Causes of death of the missing animals could not be confirmed because their carcasses were never located or fully necropsied, thus researchers were unable to directly attribute the deaths to oil contamination. However, retrospective evaluation shows it highly likely that oil exposure contributed to their deaths or did so indirectly for orphaned calves. Deterioration of the social structure of AB pod, with subgroups traveling independently from the pod and certain members no longer consistently associating with their closest relatives, was an additional probable outcome of the spill (Matkin et al. 2003). The spill may have also contributed to AT1 pod's failure to produce any offspring since 1984 (see Matkin et al. 2003). AB pod began recovering in 1996, but is not projected to regain its pre-spill size until about 2015 (Matkin et al. 2003). Five other resident pods seen swimming through oil-sheened waters after the spill did not experience losses (Matkin et al. 1994). However, these pods likely spent less time in the spill area and were observed only in lighter sheens (C. O. Matkin, pers. comm.), which suggests that lesser degrees of exposure may not have been harmful to the whales.

Live-captures for aquaria. Killer whales have been immensely popular as display animals in the world's aquaria since the 1960s and currently represent the third most widely kept species of toothed whale after bottlenose dolphins (*Tursiops truncatus*) and belugas (Kastelein et al. 2003). Interest in the live-capture of killer whales for public exhibition began in southern California in 1961, when Marineland of the Pacific captured a disoriented individual in California, which died shortly after (Bigg and Wolman 1975). An attempt to obtain a replacement animal followed at Haro Strait in 1962, but ended in the deaths of a female and possibly an accompanying male (Hoyt 1990). However, in 1964 and 1965, single whales were caught and held for periods of 3 and 12 months at the Vancouver Public Aquarium and Seattle Marine Aquarium, respectively, resulting in much publicity and demonstrating the species' highly appealing qualities when held in captivity. The development of a netting technique in 1965, the initiation of commercial netting operations in 1968, and an immediate demand for captive animals led to large increases in capture effort beginning in 1967 (Bigg and Wolman 1975). With the exception of an individual collected in Japan in 1972, Washington and British Columbia served as the only source of captive killer whales until 1976 (Hoyt 1990, OrcaInfo 1999).

Operators working in Washington and British Columbia captured most whales by following a pod until it entered an appropriate bay, where netting could be done (Bigg and Wolman 1975). Nets were then quickly placed across the bay's entrance or pursed around the pod. The whales were held for several days or longer, which allowed them to calm down and be sorted for permanent keeping or release. Puget Sound was preferred as a capture site because it offered fewer escape routes and a number of bays with shallower waters, both of which aided netting efforts, and it had a large network of shore-based observers that provided movement updates on the whales (Bigg and Wolman 1975). Important capture sites included Penn Cove on Whidbey Island (102-113 whales captured), Carr Inlet at the southern end of the Kitsap Peninsula (60-70 whales captured), and Yukon Harbor on the eastern side of the Kitsap Peninsula (40-48 whales captured) (Table 2). During these efforts, many individual whales were caught multiple times.

Table 2. Number of killer whales captured, retained for captivity, and killed during capture from 1962-1977 in Washington and British Columbia (Bigg and Wolman 1975, Asper and Cornell 1977, Hoyt 1990, Olesiuk et al. 1990a).

Date[a]	Location	No. of whales caught[b]	No. of whales retained	No. of whales dying
Southern residents				
Sept 1962	Haro Strait, Wash.[c]	1[d,e]	0	1-2[d,e]
Jul 1964	Saturna Island, B.C.	1	1	0
Oct 1965	Carr Inlet, Wash.	15	1	1
Jul 1966	Steveston, B.C.	1[e]	0	1
Feb 1967	Yukon Harbor, Wash.	15[e]	5	3
Feb 1968	Vaughn Bay, Wash.	12-15	2	0
Oct 1968	Yukon Harbor, Wash.	25-33	5	0
Apr 1969	Carr Inlet, Wash.	11[e]	2	0
Oct 1969	Penn Cove, Wash.	7-9[e]	0	1
Feb 1970	Carr Inlet, Wash.	6-14[e]	1	0
Aug 1970	Penn Cove, Wash.	80	7	4
Aug 1970	Port Madison, Wash.	1[e,f]	1	0
Aug 1971	Penn Cove, Wash.	15-24	3	0
Nov 1971	Carr Inlet, Wash.	19	2	0
Mar 1972	Carr Inlet, Wash.	9-11	1	0
Mar 1973	Ocean City, Wash.	1[e,f]	1	0
Aug 1973	Pedder Bay, B.C.	2	1	0
Aug 1973	Pedder Bay, B.C.	2	2	0
Aug 1977	Menzies Bay, B.C.	1[e]	1	0
Subtotal		224-256	36	11-12
Northern residents				
Jun 1965	Namu, B.C.	2	1	0
Jul 1967	Port Hardy, B.C.	1	1	0
Feb 1968	Pender Harbour, B.C.	1	0	0
Apr 1968	Pender Harbour, B.C.	7	6	0
Jul 1968	Malcolm Island, B.C.	11[g]	1	0
Dec 1969	Pender Harbour, B.C.	12	6	0
Subtotal		34	15	0
Transients				
Mar 1970	Pedder Bay, B.C.	5	2[h]	1
Aug 1975	Pedder Bay, B.C.	6	2	0
Mar 1976	Budd Inlet, Wash.	6	0	0
Subtotal		17	4	1
Total		275-307	55	12-13

[a] Captures are listed chronologically for Washington, followed by British Columbia.

[b] The exact numbers of whales caught in Washington were often not known due to poor record keeping and the difficulty in counting the numbers of individuals present in large groups (M. A. Bigg in Hoyt 1990).

[c] The exact location in Haro Strait is not known (Hoyt 1990), but is presumed here to have been in Washington.

[d] An adult female was shot and killed after being captured, but an adult male was also shot once during the incident (Hoyt 1990). Bigg and Wolman (1975) and Olesiuk et al. (1990a) presumed that the male also died, but based on Hoyt's (1990) account, there is no conclusive evidence of this (also see Asper and Cornell 1977).

[e] Presumed to be southern residents (Olesiuk et al. 1990a).

[f] Captured after stranding (Bigg and Wolman 1975).

[g] Presumed to be northern residents (Olesiuk et al. 1990a).

[h] Bigg and Wolman (1975) and Asper and Cornell (1977) listed three whales as being retained from this capture, but the accounts of Hoyt (1990) and Ford and Ellis (1999) disclosed the death of an adult female from apparent malnutrition in its holding pen. Her carcass was then secretly disposed of.

From 1962-1977, 275-307 whales were captured in Washington and British Columbia, of which 55 were transferred to aquaria, 12 or 13 died during capture operations, and 208-240 were released or escaped back into the wild (Table 2). However, these figures exclude a few additional deaths that were never made public (K. C. Balcomb, pers. comm.). Most (224-256) of the captures occurred in Washington, with 31 whales collected for aquaria and at least 11 dying (Table 2). Peak harvest years occurred from 1967-1971, when 80% of the retained whales were caught. Due to public opposition (e.g., Haley 1970), capture operations declined significantly after 1971, with only eight whales removed beyond this date. The British Columbia provincial government prohibited further live-captures in 1975, although an injured female calf was sent to an aquarium for permanent rehabilitation in August 1977 (Hoyt 1990, Dahlheim and Heyning 1999). In 1982, the British Columbia government issued a final license to capture killer whales in Pedder Bay, but the license holder was unable to catch any whales because none entered the bay (R. W. Baird, pers. comm.). The Washington State Senate passed a resolution (Senate Resolution 1976-222) requesting the U.S. federal government to establish a moratorium on harassment, hunting, and live-capture of the species in 1976 after six transient whales were caught in Budd Inlet, Olympia (see Hoyt [1990] for an account of the events surrounding this capture). The total revenue generated from the sale of whales captured in Washington and British Columbia probably exceeded $1,000,000, with the prices of individual animals ranging from about $8,000 in 1965 to $20,000 in 1970 (Bigg and Wolman 1975).

Based on slightly updated information from that presented by Olesiuk et al. (1990a), 70% (47 or 48 animals) of the whales retained or killed were southern residents, 22% (15 animals) were northern residents, and 7% (5 animals) were transients. For the southern resident community, collections and deaths were biased toward immature animals (63% of the total) and males (57% of identified animals). Removed whales included 17 immature males, 10 immature females, nine mature females, seven or eight mature males, and four (three immatures, one adult) individuals of unknown sex. Only 15 of the whales were subsequently identified by pod, with nine animals coming from K pod, five from L pod, and one from J pod (Bigg 1982). These removals substantially reduced the size of the southern resident population, which did not recover to estimated precapture numbers until 1993 (Baird 2001). Furthermore, selective removal of younger animals and males produced a skewed age- and sex-composition in the population, which probably worked to slow later recovery (Olesiuk et al. 1990a).

Although live-captures of killer whales ceased in the northeastern Pacific after 1977, the demand for captive individuals by aquaria continued. From 1976-1997, 55 whales were taken from the wild in Iceland, 19 from Japan, and three from Argentina (Sigurjónsson and Leatherwood 1988, Hoyt 1990, OrcaInfo 1999). These figures exclude any animals that may have died during capture. The value of captured animals rose to $200,000-300,000 per whale by 1980 (Hoyt 1990) and is now estimated at up to $1 million (Whale and Dolphin Conservation Society 2003). Live-captures fell dramatically in the 1990s, and by 1999, about 40% of the 48 animals on display in the world were captive born (OrcaInfo 1999). Captures temporarily ended in 1997, but resumed in September 2003, when one young whale was caught and another accidentally killed in the Russian Far East (Whale and Dolphin Conservation Society 2003).

POPULATION STATUS

Global Status: Past and Present

Little information on the former abundance of killer whales is currently available from any portion of their range. Scammon (1874), who worked primarily in the northeastern Pacific, considered the species as "not numerous" in comparison to other delphinids, but anecdotal remarks such as this provide little basis for recognizing even gross changes in population levels during the past 200 years. Nevertheless, it is likely that many populations have declined significantly since 1800 in response to greatly diminished stocks of fish, whales, and pinnipeds in the world's oceans (Reeves and Mitchell 1988a).

Killer whales have proven difficult to census in many areas because of their general scarcity as well as their widespread and often unpredictable movement patterns (Ford 2002). Many older characterizations of relative abundance may well reflect the amount of observation effort rather than actual differences in density among sites (Matkin and Leatherwood 1986). During the past few decades, populations have been surveyed primarily through the use of photo-identification studies or line-transect counts (Forney and Wade in press). Photo-identification is capable of providing precise information on population size, demographic traits, and social behavior (Hammond et al. 1990), making it the preferred method in locations where the species is regularly seen. It requires intensive effort spread over multi-year periods and, due to the species' mobility, should be conducted over large geographic areas to obtain accurate results. Photo-identification catalogs for killer whales were first established in the early 1970s for the resident communities of Washington and British Columbia (Balcomb et al. 1980, Sugarman 1984, Bigg et al. 1987, van Ginneken et al. 1998, 2000, 2005, Ford and Ellis 1999, Ford et al. 2000) and have since been initiated for most areas where population studies have been undertaken (e.g., Heise et al. 1991, Black et al. 1997, Dahlheim 1997, Dahlheim et al. 1997, Matkin et al. 1999a). All photographic surveys rely on recognition of individual animals through their distinctive dorsal fins and saddle patches, although eye-patch traits are sometimes used to supplement identification (Baird 1994, Visser and Mäkeläinen 2000). Line-transect surveys from ships or aircraft have generally been undertaken in large areas of open ocean where photo-identification is impractical. The results of line-transect surveys are almost always accompanied by large confidence limits, making it difficult to establish true population sizes and to compare trends over time. Furthermore, the technique is unsuited for gathering most demographic data.

As top-level predators, killer whales occur in low densities throughout most of their geographic range. Densities are typically much greater in colder waters with higher productivity than in tropical regions (Forney and Wade in press). Reeves and Leatherwood (1994) reported the worldwide population as probably exceeding 100,000 whales, based on information presented in Klinowska (1991), but this was undoubtedly an overestimate influenced by preliminary count data from the Antarctic. Forney and Wade (in press) have recently revised this figure to a minimum of about 50,000 animals. A number of regional abundance estimates have been made in recent years, with emerging evidence suggesting that many populations are relatively small (Whale and Dolphin Conservation Society 2002, Forney and Wade in press). In the northeastern Pacific, at least 2,250-2,700 resident, transient, and offshore whales are currently thought to exist from California to the western Aleutian Islands and Bering Sea (see population estimates below). Estimates for other northern populations include 500-1,500 animals in Norwegian coastal waters (Christensen 1988) and about 190 whales off Iceland (Klinowska 1991). New Zealand's entire population is believed to number fewer than 200 animals (I. N. Visser, unpubl. data). A recent population estimate of about 25,000 killer whales in Antarctica (Branch and Butterworth 2001) is considered much more accurate than earlier projections (Hammond 1984; Butterworth et al. 1994; T. A. Branch, pers. comm.). Densities in this region are highest near the ice edge (Kasamatsu et al. 2000). An estimate of 8,500 killer whales for the eastern tropical Pacific, as derived from shipborne surveys (Wade and Gerrodette 1993), is probably far too large, given that densities are substantially reduced at lower latitudes. Abundance in many other areas remains poorly investigated (Whale and Dolphin Conservation Society 2002). Trend information is lacking for virtually all populations other than several resident and the AT1 transient communities of the northeastern Pacific.

Status of Southern Resident Killer Whales

Status before 1974. Several lines of evidence argue that the southern resident community may have numbered more than 200 whales until perhaps the mid- to late-1800s (Krahn et al. 2002), when Euro-American settlement began to impact the region's natural resources. Recent genetic investigations using microsatellite DNA reveal that the genetic diversity of the population resembles that of the northern residents (Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001), indicating that the two were possibly once similar in size. This scenario would be unlikely if the southern resident population had remained small for many generations, which would have caused a gradual loss of genetic diversity. The presence of relatively few acoustic clans and pods in the southern residents (1 clan, 3 pods), as compared to the northern (3 clans, 16 pods) and southern Alaska residents (2 clans, 11 pods), also implies that the southern population was once larger (Krahn et al. 2002). Finally, reductions in salmon and other prey along much of the west coast of North America during the past 150 years, especially from Washington to California (Nehlson 1997, Kope and Wainwright 1998), have very likely lessened the region's carrying capacity for resident killer whales (Krahn et al. 2002) and caused a decline in southern resident abundance.

Efforts to determine killer whale population trends in the northeastern Pacific during the past century are hindered by an absence of empirical information prior to 1974. A report by Scheffer and Slipp (1948) is the only older account to mention abundance in the core range of the southern residents. It noted that the species was "frequently seen" during the 1940s in the Strait of Juan de Fuca, northern Puget Sound, and off the coast of the Olympic Peninsula, with smaller numbers occurring farther south along Washington's outer coast. Palo (1972) put forth a tentative estimate of 225-300 whales for Puget Sound and the Georgia Basin in 1970, but was admittedly unsure of the figure's validity. The authors of both reports were unaware of the different forms of killer whales, thus their remarks pertained to residents, transients, and offshores combined.

Olesiuk et al. (1990a) modeled the population size of the southern resident community between 1960 and 1973 and projected an increase in numbers from about 78 to 96 whales from 1960 to

Table 3. Population and pod sizes of southern and northern resident killer whales in Washington and British Columbia, 1960-2004.

	Southern residents[a]				Northern residents[b]
Year	J pod	K pod	L pod	Total	Total
1960	-	-	-	78	97
1961	-	-	-	79	98
1962	-	-	-	82	101
1963	-	-	-	85	105
1964	-	-	-	90	110
1965	-	-	-	94	117
1966	-	-	-	95	115
1967	-	-	-	96	119
1968	-	-	-	89	120
1969	-	-	-	81	111
1970	-	-	-	80	108
1971	-	-	-	67	113
1972	-	-	-	69	115
1973	-	-	-	71	121
1974	15	16	39	70	123
1975	15	15	41	71	132
1976	16	14	40	70	131
1977	18	15	46	79	134
1978	18	15	46	79	137
1979	19	15	47	81	140
1980	19	15	49	83	147
1981	19	15	47	81	150
1982	19	14	45	78	151
1983	19	14	43	76	155
1984	17	14	43	74	156
1985	18	14	45	77	163
1986	17	16	48	81	171
1987	18	17	49	84	177
1988	19	18	48	85	180
1989	18	17	50	85	187
1990	18	18	53	89	194
1991	20	17	55	92	201
1992	19	16	56	91	199
1993	21	17	59	97	197
1994	20	19	57	96	202
1995	22	18	58	98	205
1996	22	19	56	97	212
1997	21	19	52	92	220
1998	22	18	49	89	216
1999	20	17	48	85	216
2000	19	17	47	83	209
2001	20	18	43	81	201
2002	20	19	44	83	202
2003	22	20	42	84	204
2004	23	21	44	88	-

[a] Southern resident data from 1960-1973 are estimates based on projections from the matrix model of Olesiuk et al. (1990a). Data from 1974-2004 were determined through photo-identification surveys and were provided by the Center for Whale Research (unpubl. data). Data for these years represent the number of whales present at the end of each calendar year. Whales verified as missing are assumed to have died and may be removed from count totals within a calendar year, depending on date of disappearance (K. C. Balcomb, pers. comm.). Numbers for L pod and the entire southern resident community from 2001-2004 include L98.

[b] Northern resident data from 1960-1974 are estimates based on projections from the matrix model of Olesiuk et al. (1990a). Data from 1975-2004 were determined through photo-identification surveys and were provided by J. K. B. Ford (unpubl. data). Count data represent the number of whales believed to be alive during a calendar year. Whales are counted through their last year of being seen (J. K. B. Ford, pers. comm.).

1967 (Table 3, Figure 7). This was probably a result of the population recovering from the opportunistic shooting that was widespread before 1960 (see *Mortality Associated with Killer Whale Depredation*) and other human impacts, or may have been caused by some unidentified improvement in the region's capacity to support the whales (Olesiuk et al. 1990a). Beginning in about 1967, removals of whales by the live-capture fishery caused an immediate decline in southern resident numbers (see *Live-Captures for Aquaria*). The population fell an estimated 30% to about 67 whales by 1971 (Olesiuk et al. 1990a). Removals from the southern resident community are known to have included nine animals from K pod, five from L pod, and one from J pod (Bigg 1982).

Status from 1974-2003. Photo-identification studies have been the foundation of all southern resident research since the early 1970s. Annual censuses of the community were initiated by Michael Bigg of Canada's Department of Fisheries and Oceans in 1974 (Bigg et al. 1976). The Center for Whale Research assumed responsibility for the counts in 1976 (Balcomb et al. 1980) and has directed them since then. The surveys are typically performed from May to October, when all three pods reside near the San Juan Islands, and are considered complete censuses of the entire population. It should be noted that small discrepancies in the annual count totals of the southern residents (e.g., see Ford et al. [2000], Baird [2001], Taylor and Platt [2001], Krahn et al. [2002, 2004a], and Table 3 of this report) are due in part to differences in the reporting times of yearly numbers and whether or not whales that died were tallied during the year of their death. The count criteria used in this report appear in Table 3 and Figures 7 and 8.

The population has gone through several periods of growth and decline since 1974 (Table 3, Figure 7), when live-captures were ending and numbers were judged as beneath carrying capacity (Olesiuk et al. 1990a). Between 1974 and 1980, total whale numbers expanded 19% (mean annual growth rate of 3.1%) from 70 to 83 animals. J and L pods grew 27% and 26%, respectively, during this period, whereas K pod decreased by 6%.

This was followed by four consecutive years of decrease from 1981-1984, when count results fell 11% (mean annual decline rate of 2.7%) to 74 whales. The decline coincided with periods of fewer births and greater mortality among adult females and juveniles (Taylor and Plater 2001). A distorted age- and sex-structure, likely caused by the selective cropping of animals during live-captures 8-17 years earlier, also appears to have been a significant factor in the decline (Olesiuk et al. 1990a). This resulted in fewer females and males maturing to reproductive age and a reduction in adult males that was possibly below the number needed for optimal reproduction. An unusually large cohort of females that stopped bearing young also played a role in the decline (Olesiuk et al. 1990a). Pod membership during this period dropped by 12% for L pod, 11% for J pod, and 7% for K pod (Table 3, Figure 8).

In 1985, the southern residents entered an 11-year growth phase, which began with a drop-off in deaths and a pulse in births caused partly by the maturation of more juveniles (Taylor and Plater 2001). Total numbers eventually peaked at 98 animals in 1995 (Table 3, Figure 7), representing an increase of 32% (mean annual growth rate of 2.9%) in the population. Pod growth during the period was 37% in L pod, 36% in K pod, and 29% in J pod (Table 3, Figure 7).

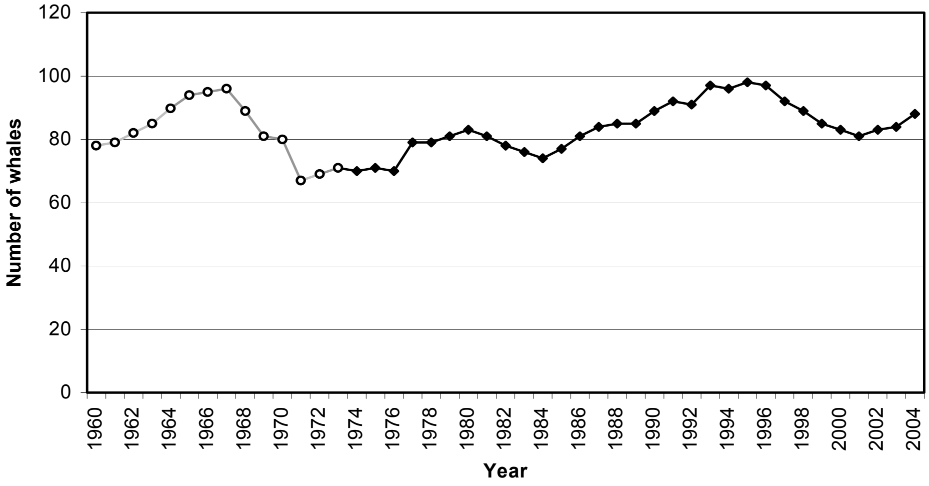


Figure 7. Population size and trend of southern resident killer whales, 1960-2003. Data from 1960-1973 (open circles, gray line) are number projections from the matrix model of Olesiuk et al. (1990a). Data from 1974-2003 (diamonds, black line) were obtained through photo-identification surveys of the three pods (J, K, and L) in this community and were provided by the Center for Whale Research (unpubl. data). Data for these years represent the number of whales present at the end of each calendar year.

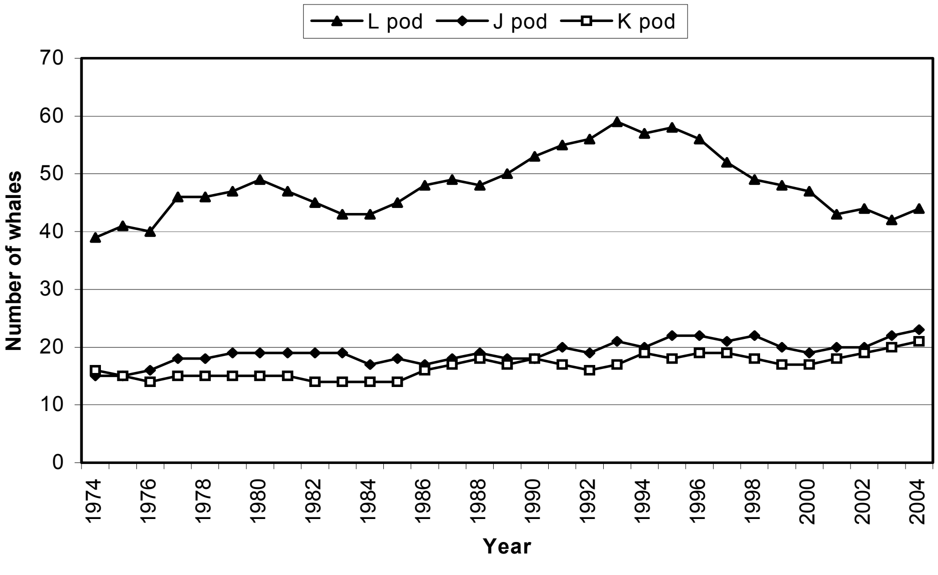


Figure 8. Population sizes and trends of the three southern resident killer whale pods (J, K, and L) from 1974-2003. Data were obtained through photo-identification surveys and were provided by the Center for Whale Research (unpubl. data). Data represent the number of whales present in each pod at the end of a calendar year (K. C. Balcomb, pers. comm.).

The southern resident community entered yet another period of decline in 1996, with a 17% reduction (mean annual decline rate of 2.9%) in numbers occurring by 2001, when 81 whales remained (Table 3, Figure 7). All three pods suffered reductions in membership during this period, with L pod falling 28%, J pod 14%, and K pod 11% (Table 3, Figure 8). There is no indication that this decline was caused by any lingering demographic effects related to the live-capture era (Taylor 2004). Instead, it appears to have resulted more from an unprecedented 9-year span of relatively poor survival in nearly all age classes and both sexes and secondarily from an extended period of poor reproduction (Krahn et al. 2002, 2004a). During this decline, the status of L pod began to attract special concern because of its poor performance compared to J and K pods, including greater than normal mortality and lower fecundity (Taylor 2004).

The population reversed its trend again in 2002 and had grown to 88 whales at the end of 2004 (Table 3, Figure 8). Growth by J and K pods account for most of this gain and both pods now exceed their largest sizes achieved in the 1990s. By comparison, L pod declined to just 42 members in 2003, but grew to 44 animals in 2004. This pod has experienced means of 2.7 deaths and 1.4 births per year since 1994 (Center for Whale Research, unpubl. data).

At present, the southern resident population has declined to essentially the same size that was estimated during the early 1960s, when it was considered as likely depleted (Olesiuk et al. 1990a). Since censuses began in 1974, J and K pods have increased their sizes by 53% (mean of 1.8% per year) and 31% (mean of 1.0% per year), respectively. The largest pod, L pod, has grown 12.8% (mean of 0.4% per year) during this period, but more importantly, experienced a 10-year decline from 1994-2003 that threatened to reduce the pod's size below any previously recorded level. Despite hopeful data from 2002-2004 indicating that L pod's decline may have finally ended, such a conclusion is premature. From 1974-2003, there was an average of 3.3 births and 2.6 deaths per year in the community as a whole (Center for Whale Research, unpubl. data).

Olesiuk et al. (1990a) used data from 1974-1987 to estimate an intrinsic growth rate of 2.92% per year for both resident populations combined. However, observed rates of increase differed substantially for the two communities (1.3% annually from 1974-1987 for the southern residents vs. 2.9% annually from 1979-1986 for the northern residents). Brault and Caswell (1993) also examined growth rates for both populations during the same periods, but used a stage-structured model and based their calculations on females only. Intrinsic and observed rates of growth among the southern residents were 2.5% and 0.7% per year, respectively, with the observed rate being much lower than in the northern residents. Non-significant differences in intrinsic growth rates existed among the three southern pods (J pod, 3.6% per year; K pod, 1.8% per year; and L pod, 1.5% per year). This study concluded that population growth rates in killer whales were more sensitive to changes in adult survival, as would be expected in any long-lived species, than to changes in juvenile survival and fertility.

Using data from 1974-2003, Krahn et al. (2002, 2004a) further analyzed the population dynamics of the southern residents in an effort to identify demographic factors contributing to the population's latest decline. For their analyses, six age and sex classes were defined as follows: calves in their first summer (<1 year of age), juveniles of both sexes (1-10 years of age), females of reproductive age (11-41 years of age), post-reproductive females (42 years of age and older), young adult males (11-21 years of age), and older males (22 years of age and older). These studies found sizable differences in annual survival among age and sex classes, with an overall mean of 0.969 from 1974-2000 (Krahn et al. 2002). Modeling of annual survival data determined that overall survival was relatively constant within approximately seven-year periods, but differed greatly between consecutive periods (Figure 9; Krahn et al. 2004a). Greater than average survival rates were detected from 1974-1979, 1985-1992, and 2001-2002, but rates were below average from 1980-1984 and 1993-2000. Changes in survival were not related to stochastic variation caused by the population's small size (e.g., random patterns in births or deaths) or to annual fluctuations in survival. Krahn et al. (2002) therefore suggested that survival patterns were more likely influenced by an external cause, such as periodic changes in prey availability or exposure to environmental contaminants. The lowest rates of survival in each of the population's six age and sex categories occurred from 1993-2000 (Krahn et al. 2004a). Survival fell most sharply in older males, whereas reproductive females showed the smallest decline in survival (Figure 10). From 1993-2001, the percentage of males 15 years of age or older in the population fell from 17% to 11% (Krahn et al. 2002), placing it much lower than the 19% necessary for a stable age and sex distribution (Olesiuk et al. 1990a). Investigation of temporal patterns in survival rates found no differences among the three pods (Figure 11; Krahn et al. 2004a). Each pod experienced simultaneous reductions in survival during the declines of the early 1980s and the late 1990s. However, L pod has consistently displayed lower survival rates than J and K pods.

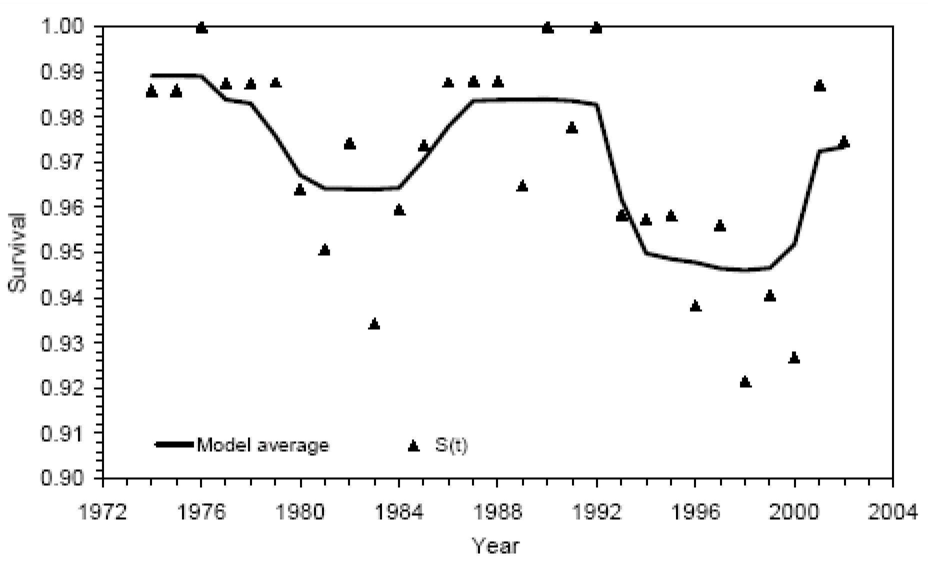


Figure 9. Model-averaged estimates of crude survival (black line) for the entire southern resident population, 1974-2002 (Krahn et al. 2004a). Annual survival levels are represented by triangles.

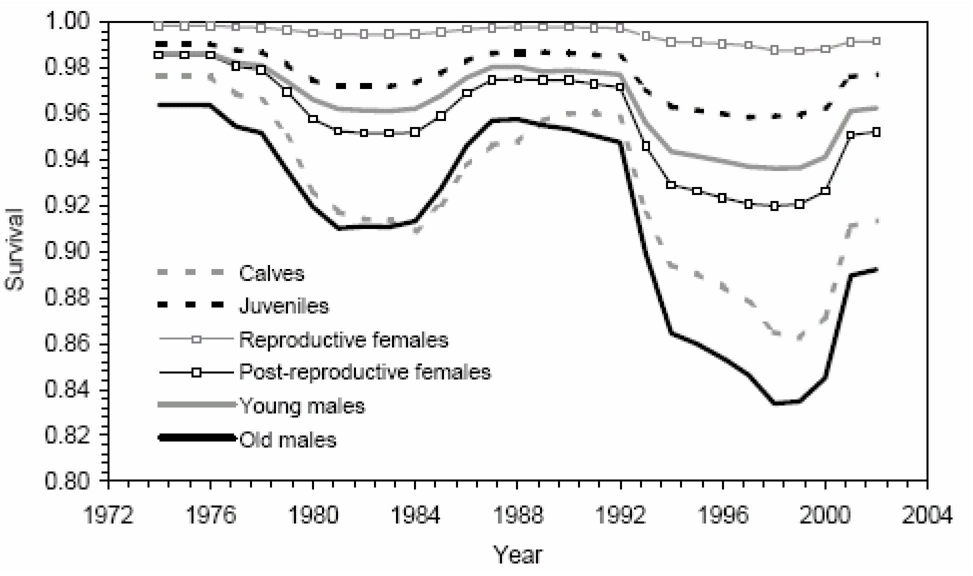


Figure 10. Model-averaged estimates of survival by age and sex category for the entire southern resident population, 1974-2002 (Krahn et al. 2004a).

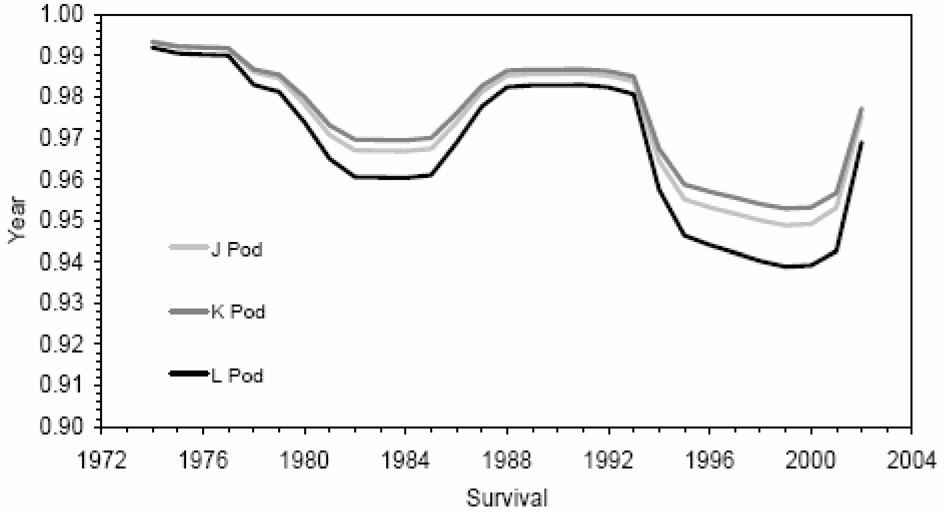


Figure 11. Annual survival estimates by pod for the southern resident population, 1974-2002 (Krahn et al. 2004a).

Krahn et al. (2002, 2004a) also examined fecundity levels in the southern resident population. Based on numbers of calves that survived to their first summer, average fecundity of reproductive-aged females was estimated at 12% from 1974-2000, which corresponded to a mean interval of 7.7 years between surviving calves. Modeling revealed that annual birth rates best fit a periodic function with about eight years between peaks (Figure 12; Krahn et al. 2004a).

Low points in the numbers of recruited calves occurred in 1974-1975, 1982, 1987, and 1996, and peaks occurred in 1976, 1985, and 1994. Considerable variability exists in the annual fecundity rate of the population, as expected in a small population with few reproductively active females (Krahn et al. 2002). However, because the data fit a periodic function, reproductive output also appears to be partially synchronized between females. Such a pattern might result from occasional poor environmental years causing high calf mortality, which might then lead to a pulse in births after conditions recovered (Krahn et al. 2002). Birthing synchrony might then be retained for a certain period of time thereafter.

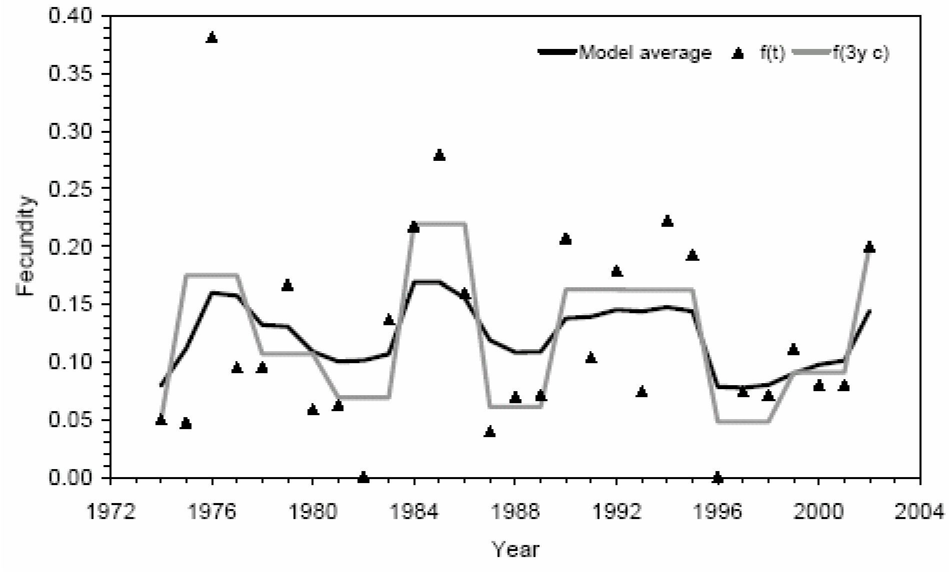


Figure 12. The best fitting model of fecundity (based on viable calves per reproductive-age female), which is a periodic function with 3-year constant periods (gray line), for the southern resident population, 1974-2002 (Krahn et al. 2004a). The model average fecundity (black line) and annual fecundity rates (triangles) for the population are also shown.

During the past decade, J and K pods appear to have increased or maintained their calf productivity when compared to the previous decade (Center for Whale Research, unpubl. data). In contrast, calf productivity in L pod has dropped by about a third in the past 10 years, with only 15 calves recorded. This may be partially due to the females of this pod having only one fully adult male from J and K pods to mate with between 1998 and 2003 (Taylor 2004, Wiles 2004). Additionally, L pod has experienced higher calf mortality (5 of 15 viable calves born during the past 11 years) than either J pod (0 of 11 viable calves) or K pod (2 of 9 viable calves) (Center for Whale Research, unpubl. data).

Brief histories of the three southern resident pods are provided below. At the end of 2004, the community as a whole had nine mature males (10.2% of the population), 24 reproductive females (27.3%), 12 post-reproductive females (13.6%), 21 juvenile males (23.9%), 10 juvenile females (11.4%), and 12 immature animals of unknown sex (13.6%) (van Ginneken et al. 2005; Center for Whale Research, unpubl. data). This contrasts with the population's structure in 1987, when about 21% of the animals were mature males, 19% were reproductive females, 15% were post-reproductive females, and 45% were juveniles of both sexes (Olesiuk et al. 1990). Older demographic information on the pods can be found elsewhere (Balcomb et al. 1980, 1982, Balcomb 1982, Bigg 1982, Balcomb and Bigg 1986, Bigg et al. 1987, Ford et al. 2000 van Ginneken et al. 2000).

J pod. This pod's overall expansion from 15 whales in 1974 to 23 whales at the end of December 2004 has been mixed with several minor declines and increases during intervening years (Table 3, Figure 8). The pod is currently comprised of four matrilines totaling one adult male, six reproductive females, two post-reproductive females, six immature males, five immature females, and three immature animals of unknown sex (van Ginneken et al. 2005; Center for Whale Research, unpubl. data). The oldest member is J2, which is estimated to be in her eighties or nineties (Ford et al. 2000). J1 is the only adult male and is thought to be in his early or mid-fifties.

K pod. Membership in K pod has varied from 14 to 21 whales since 1974, with 21 animals present at the end of 2004 (Table 3, Figure 8). The pod currently holds four matrilines consisting of one mature male, six reproductive females, three post-reproductive or non-reproductive females, six immature males, two immature females, and three immature whales of unknown sex (van Ginneken et al. 2005; Center for Whale Research, unpubl. data). The oldest member is K7, which is believed to be in her eighties or nineties (Ford et al. 2000). The pod was without an adult male for several years in the late 1990s, following the death of K1 in 1997. The oldest male (K21) is now 19 years of age. This pod was cropped especially heavily during the live-capture era (Bigg 1982).

L pod. This is the largest of the three southern resident pods and grew from 39 whales in 1974 to a peak of 59 whales in 1993 (Table 3, Figure 8). Pod membership has been largely in decline since then and totaled just 42 animals at the end of 2003, although two individuals were added during 2004. L pod currently contains 12 matrilines with seven adult males, 12 reproductive females, seven post-reproductive females, nine immature males, three immature females, and six immature animals of unknown sex (van Ginneken et al. 2005; Center for Whale Research, unpubl. data). The percentage of immatures (40.9%) is currently the lowest of any pod. Three matrilines in L pod are represented by single whales, either males or post- reproductive females, and are destined to eventually die out. The oldest females are L25 and L12, which are estimated to be 77 and 72 years old, respectively (Ford et al. 2000, van Ginneken et al. 2005). L41 and L57 are the oldest males and were both born in 1977. An additional member of L pod, a six-year-old male (L98), has lived solitarily in Nootka Sound on the west side of Vancouver Island since July 2001 after becoming separated from the pod. Canadian officials are currently assessing different methods to reunite the whale with the pod. L98 is included in the population figures used in this document, despite its isolation. During the 1980s, Hoelzel (1993) believed that L pod had separated into three smaller pods, which were identified as L8, L10, and L35 pods.

Future predictions. Several studies have used a technique known as population viability analysis (PVA) to assess the future risk of extinction of the southern resident population. PVAs rely on known life history parameters to reach their conclusions and usually assume that conditions observed in the past will continue in the future. Limitations in models can produce unreliable results for a variety of reasons, such as the use of inaccurate demographic data and failure to correctly consider environmental variables and parameter uncertainty (Beissinger and Westphal 1998, Reed et al. 1998). Thus, PVA forecasts should be viewed with some caution.

The initial PVAs of the southern residents conducted by Taylor and Plater (2001) and Krahn et al. (2002) have been recently updated by Krahn et al. (2004a), who examined demographic information from several time periods (1974-2003, 1990-2003, and 1994-2003) to estimate extinction risk. Mean survival rates varied among periods and were highest from 1974-2003 and lowest from 1994-2003. In contrast, the model used a single fecundity rate, averaged from 1974-2003, for all simulations. The study considered seven values of carrying capacity for the population ranging from 100 to 400 whales, three levels of catastrophic (e.g., oil spills and disease outbreaks) frequency ranging from none to twice per century, and three levels of catastrophic magnitude in which 0, 10, or 20% of the animals died per event. Analyses indicated that the southern residents have extinction probabilities of <0.1-3% in the next 100 years and 2-42% in the next 300 years under the scenario that the population's survival rates from 1974-2003 continue into the future. However, the likelihood of extinction was greater if future survival rates match those from 1990-2003 or 1994-2003. The most pessimistic predictions were associated with survival rates from 1994-2003, with extinction risks predicted at 6-19% in 100 years and 68-94% in 300 years. In all cases, higher extinction risks were linked to lower carrying capacities and more frequent and severe catastrophes. Krahn et al. (2004a) also assessed the population's probability of slipping to a level of "quasi-extinction," which was defined as the stage at which 10 or fewer males or females remained, thereby representing a threshold from which the population was not expected to recover. These simulations suggested that the southern residents have a 1-15% chance of reaching quasi-extinction in the next 100 years and a 4-68% chance in the next 300 years if survival rates from 1974-2003 continue. Predictions were again most pessimistic using survival data from 1994-2003, with the risk of quasi-extinction predicted at 39-67% in 100 years and 76-98% in 300 years. As before, higher risks within each category were tied to smaller carrying capacities and greater threats of catastrophic events.

Status of Other Killer Whale Communities in the Northeastern Pacific

Population assessments of other regional killer whale population provide useful insight into the status of the southern residents and are briefly summarized here.

Northern residents. As with the southern residents, this population was also in a depleted condition when researchers recorded 132 whales during an initial census in 1975. Although count data are not available before this date, modeling by Olesiuk et al. (1990a) suggests that the community expanded from about 97 to 120 whales between 1960 and 1968, then declined by an estimated 10% to about 108 whales 1970 due to removals for aquaria (Table 3, Figure 13). Causes of declines before 1960 probably resembled those for southern residents, with indiscriminate shooting and other human-related factors most likely involved (Olesiuk et al. 1990a).

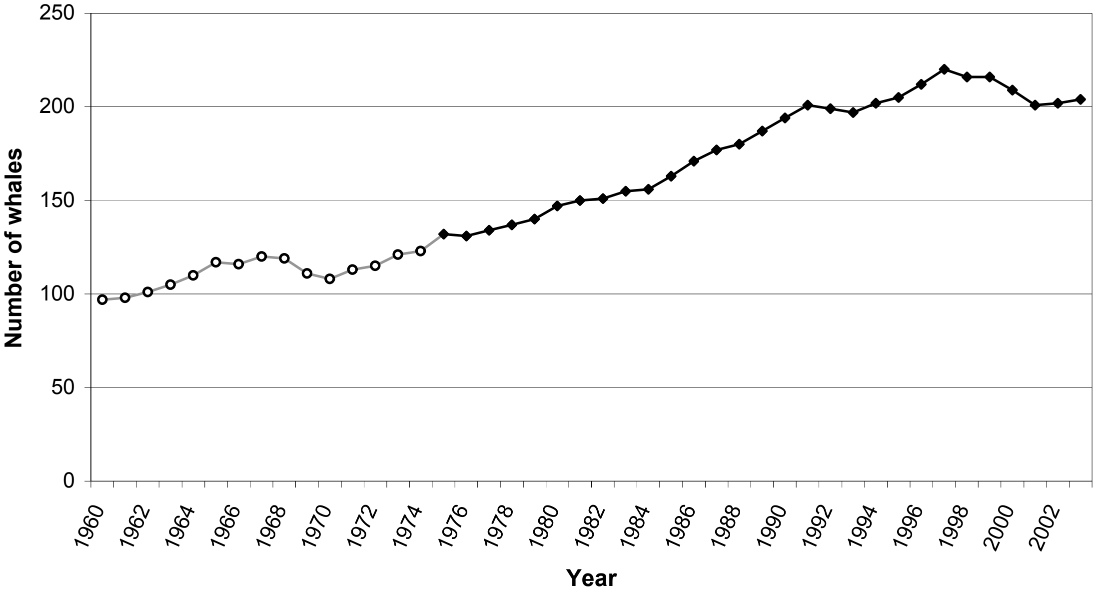


Figure 13. Population size and trend of northern resident killer whales, 1975-2003. Data from 1960-1974 (open circles, gray line) are number projections from the matrix model of Olesiuk et al. (1990a). Data from 1975-2003 (diamonds, black line) were obtained through photo-identification surveys of the 16 pods in this community and were provided by J. K. B. Ford (unpubl. data). Data for these years represent whale numbers for entire calendar years; animals are counted through their last year seen.

Annual censuses of the northern residents have been conducted since 1975 (Bigg et al. 1990, Ford et al. 2000). These documented fairly steady growth in the population at a mean rate of 3.0% per year from 1975-1997, when numbers expanded from 132 to 220 whales (Table 3, Figure 13) (Ford et al. 2000; J. K. B. Ford, unpubl. data). This rate of growth was similar to the predicted intrinsic rate of the population and was substantially higher than the observed rate of the southern residents during the same time (Olesiuk et al. 1990a, Brault and Caswell 1993). Several factors were presented as possible reasons for the relatively stable growth of the northern residents through 1997, including 1) the population's larger size in comparison to the southern residents, which made it less sensitive to stochastic events in births and deaths, 2) the smaller amount of cropping that occurred during the live-capture fishery (Olesiuk et al. 1990a), and 3) possibly fewer environmental changes in the community's geographic range in recent decades. The population experienced an 8.6% decline in numbers from 1997-2001, falling to 201 whales. Possible explanations for this decrease are similar to those put forth for the southern residents (J. K. B. Ford, pers. comm.). Abundance has increased slightly since then, with 204 whales counted in 2003. PVAs have not been conducted for this population.

Southern Alaska residents. In contrast to the losses experienced by AB pod after the *Exxon Valdez* oil spill (see *Incidental human-related mortality*), most pods in this community have steadily expanded in size since 1984, when annual censuses began (Matkin et al. 2003). Count data exist for 11 pods in which membership is completely known. Excluding AB pod, the aggregate number of whales in seven pods from Prince William Sound and Kenai Fjords increased from 82 to 118 animals between 1984 and 2001, with five pods growing and two maintaining their size. Three other pods primarily inhabiting southeastern Alaska expanded from a total of 39 animals to 85 animals during this period. The combined annual growth rate for these 10 pods averaged 4.0% per year, exceeding that recorded for the northern residents from the mid-1970s to late 1990s and the southern residents during the 1970s and from the mid-1980s to mid-1990s. Differences in the reproductive lifespan of females and calf output probably explain this greater rate of growth (Matkin et al. 2003). AB pod reversed its decline in 1996 and is now also increasing (Matkin et al. 2003). Although census data are incomplete for other pods in the population, the current total size of the southern Alaska resident community is estimated to number at least 501 whales (Angliss, in prep.; C. O. Matkin, unpubl. data). The population's strong growth rate since 1984 suggests that the community has either been recovering from an artificially depleted condition that existed when censuses began or that environmental conditions (e.g., salmon abundance) have improved since the mid-1980s (Matkin et al. 2003). Unlike with the southern and northern residents, no decline in abundance was detected among the southern Alaska residents between the mid-1990s and 2001.

Western Alaska residents. Based on photo-identification studies, the minimum size of this population has been variously listed as 505 whales (Angliss, in prep.) and 800 whales (Krahn et al. 2004a). Population trend data are unavailable.

West coast transients. This community also suffered serious prey losses between the late 1800s and late 1960s, and very likely experienced a sizable decrease in abundance as a result (Ford and Ellis 1999, Springer et al. 2003). During this period, overhunting caused dramatic declines or extirpations in pinniped and large whale populations along much of western North America. By about 1970, it is estimated that harbor seal and Steller's sea lion populations in British Columbia had fallen to about 10% and 25-33%, respectively, of historic levels (Olesiuk et al. 1990b, Ford and Ellis 1999). Similar reductions in pinniped numbers occurred elsewhere between southeastern Alaska and California (Scammon 1874, Scheffer 1928, Bonnot 1951, Newby 1973, Jeffries et al. 2003). Many large whale populations have also severely declined and have never recovered (Scheffer and Slipp 1948, Rice 1974, Gregr et al. 2000, Springer et al. 2003, Carretta et al. 2004). However, seal numbers in the region have grown 7 to 12-fold since about 1970 and are now close to or at carrying capacity (Olesiuk 1999, Jeffries et al. 2003). Recovery of the gray whale population (National Marine Fisheries Service 1993) and partial recovery of regional humpback whale populations have also occurred (Carretta et al. 2004). With the recovery of some pinniped populations, Ford et al. (2000) believed that transient whales no longer face a scarcity of prey.

Cumulative numbers of photographically identified west coast transients expanded throughout the 1980s and 1990s as efforts to document the population continued (Bigg et al. 1987, Black et al. 1997, Ford and Ellis 1999). To date, about 320 individuals have been identified in the population, which includes about 225 transients in Washington, British Columbia, and southeastern Alaska (Ford and Ellis 1999; J. K. B. Ford, unpubl. data) and 105 animals off California (Black et al. 1997). At least 10 whales have been seen in both regions. Efforts to determine population size are complicated by the lack of a complete registry of individuals and the difficulty in establishing deaths over time (Ford and Ellis 1999, Baird 2001; Angliss, in prep.). Given the current level of knowledge, the population probably totals about 300-400 whales. Trend information is lacking for the population because accurate assessments of abundance have not been made.

Gulf of Alaska transients. This community contains a minimum of 314 whales, based on photo-identification data from the late 1990s to 2003 (Angliss, in prep.). Population trend has not been determined.

AT1 transients. This pod numbered 21 whales in 1988, but went into rapid decline after the *Exxon Valdez* oil spill in early 1989 and fell to just 11 members by 1992 (Matkin et al. 1999, Matkin et al. 2003, NMFS 2003). Additional deaths and a lack of births since 1984 have further reduced the pod's size to no more than eight whales as of 2004 (C. O. Matkin, unpubl. data).

Offshores. Two partial population estimates are available for offshore killer whales, but are not directly comparable because of differences in methodology and geographic coverage. Carretta et al. (2004) calculated a minimum estimate of 361 offshore whales along the coasts of Washington, Oregon, and California, as determined from shipboard line-transect surveys conducted in 1996 and 2001 and the percentage of offshore animals among all killer whales photographed off California (Black et al. 1997). Based on photo-identification studies from 1989 to 2004, 350 individual whales have been recorded in California and Alaska waters (M. E. Dahlheim, unpubl. data). This figure is considered a minimum estimate of total numbers due to the continued detection of new individuals over time and because photographic records from British Columbia, Washington, and Oregon were not included in the analyses (M. E. Dahlheim, pers. comm.). Difficulties in substantiating mortalities and recognizing previously identified individuals not seen for long periods further complicate efforts to determine the size of this community using this technique.

LEGAL STATUS

Federal laws. Killer whales and other marine mammal populations in the United States are protected under the Marine Mammal Protection Act of 1972 (MMPA), which placed a moratorium on the taking (defined as harassing, hunting, capturing, killing, or attempting to harass, hunt, capture, or kill) and importation of these animals and products derived from them. The MMPA exempts some native harvest for subsistence purposes and for creating and selling native handicrafts and clothing, but no tribe currently has a harvest permit approved for killer whales. Some incidental take associated with commercial fisheries is also allowed. The MMPA allows permits to be issued for research, public display, and commercial/educational photography. In late 2003, the Department of Defense was granted an exemption from the take and harassment provisions of the MMPA during times of national emergency. The southern resident and AT1 transient stocks were declared depleted stocks under the MMPA by the

National Marine Fisheries Service in May 2003 and July 2004, respectively (National Marine Fisheries Service 2003b, 2004a). This status allows the agency to develop conservation measures aimed at improving the habitat of both populations and elevating public awareness. In response to a petition filed by a number of environmental organizations in 2001 (Center for Biological Diversity 2001), the Service determined that listing the southern residents as threatened or endangered under the U.S. Endangered Species Act (ESA) was "not warranted" because the population did not meet the criteria of being a distinct population segment of the worldwide killer whale taxon (Krahn et al. 2002, National Marine Fisheries Service 2002). This decision was challenged in federal court in December 2003, and the court remanded the decision to NMFS to re-evaluate its initial determination. Upon further review of taxonomic relationships, the Service determined in December 2004 that the southern residents are discrete and significant with respect to an unnamed subspecies of killer whales (North Pacific Residents), and proposed that they be listed as threatened under the ESA (National Marine Fisheries Service 2004b).

Cetaceans also receive protection through the Packwood-Magnuson Amendment of the Fisheries and Conservation Act. This law allows observers to be placed on fishing vessels that have a high probability of killing marine mammals and provides for limited monitoring and enforcement activities regarding marine mammal and vessel interactions. The Pelly Amendment of the Fisherman's Protective Act allows trade sanctions to be imposed on countries that violate international laws protecting marine mammals. The importation of wildlife and associated products taken illegally in foreign countries is prohibited under the Lacey Act.

Canadian federal laws. Killer whales received federal protection from disturbance under Canada's Marine Mammal Regulations of the Fisheries Act in 1994, when a change in definitions extended coverage to all cetaceans and pinnipeds (Baird 2001). Although these regulations allow killer whales to be hunted with the purchase of a fishing license at a nominal fee, the license is granted at the discretion of the Minister of Fisheries and Oceans and no such licenses have ever been approved. The regulations broadly prohibit the disturbance of killer whales (except when being hunted), but give no definition of "disturbance." Penalties include fines and imprisonment. Fisheries and Oceans Canada is currently amending the regulations to make them more stringent and relevant to conservation needs (Fisheries and Oceans Canada 2002). The department has also developed a set of voluntary guidelines to limit interactions between whale-watching vessels and northern resident killer whales. Until recently, there has been little enforcement of the Marine Mammal Regulations or monitoring of the viewing guidelines by authorities (Baird 2001, Lien 2001). However, in 2004, an American whale-watching operator was prosecuted under the Marine Mammal Regulations and fined CA$6,500 (US$4,875) for approaching two groups of southern resident whales in the Gulf Islands too closely. In 2001, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) categorized the four populations of killer whales in the country's Pacific waters, as follows: southern residents, endangered; northern residents, threatened; transients, threatened; and offshores, special concern. COSEWIC had no legal mandate and served only in an advisory role. The Species at Risk Act (SARA) became federal law in June 2003, with killer whale populations maintaining their same status as under COSEWIC. Under this regulation, the killing, harassment, and possession of killer whales is prohibited. Important habitats of the whales will also eventually receive protection. Lastly, SARA requires the preparation of recovery strategies and action plans for all listed species. A recovery strategy is currently being drafted for southern and northern resident killer whales by a recovery team and will soon be followed by an action plan identifying necessary conservation activities.

Washington state laws. Killer whales were named a "state candidate species" by the Washington Department of Fish and Wildlife in June 2000, which qualified them for consideration as endangered, threatened, or sensitive under state law (Washington Administrative Code [WAC] 232-12-011 and 232-12-014). After an evaluation by the Department (Wiles 2004), the state's Fish and Wildlife Commission approved listing of the species as endangered in April 2004, with formal designation occurring in June 2004. All forms of killer whale found in the state (i.e., residents, transients, and offshores) are protected under the law. This prohibits the hunting, possession, malicious harassment, and killing of killer whales (RCW 77.15.120). Violations can be either a gross misdemeanor or a class C felony, with penalties ranging up to five years imprisonment and a $10,000 fine. The species also receives protection under WAC 232-12-064, which prohibits the capture, importation, possession, transfer, and holding in captivity of most wildlife in state. Killer whales are listed as a "Criterion Two" priority species on the Department's Priority Habitat and Species List, which catalogs animals and plants that are priorities for conservation and management, especially at the county level. Criterion Two species include those species or groups of animals susceptible to significant population declines within a specific area or statewide by virtue of their inclination to aggregate. This status provides no mandatory protection for killer whales. In some situations, federal laws may preempt the regulatory protections provided by state governments.

Other state *and provincial laws.* Although not specifically named, killer whales are covered under state regulations in Oregon (OAR 635-044-0130) and California (CF&G code, section 4500(a)) that protect all marine mammals from being killed, hunted, chased, or possessed. Neither British Columbia nor Alaska gives legal protection to killer whales.

International laws. International trade in killer whales and their body parts is regulated and monitored by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Killer whales were placed on Appendix II in 1979, which requires all international shipments of the species to be accompanied by an export permit issued by the proper management authority of the country of origin. The International Whaling Commission categorizes killer whales and most other odontocetes as "small cetaceans," but there is disagreement among member countries as to whether the Convention applies to this group of species. The Commission officially included killer whales in their moratorium on factory ship whaling (Anonymous 1981), but other management measures (e.g., the Southern Ocean Sanctuary and the moratorium on commercial whaling) do not apply to killer whales (Baird 2001). In 2002, killer whales were added to Appendix II of the U.N. Convention on the Conservation of Migratory Species of Wild Animals. This designation is given to migratory species that "have an unfavorable conservation status and require international agreements for their conservation and management, as well as those which have a conservation status which would significantly benefit from the international cooperation that could be achieved by an international agreement." The World Conservation Union (IUCN) lists killer whales as a species of "Lower Risk/Conservation Dependent" on its Red List.

POTENTIAL THREATS TO SOUTHERN RESIDENT KILLER WHALES

Marine mammal populations are often exposed to many forms of environmental degradation, including habitat deterioration, changes in food availability, increased exposure to pollutants, and human disturbance. All of these factors have been identified as potential threats to killer whales in Washington and British Columbia (Ford and Ellis 1999, Ford et al. 2000, Baird 2001, Krahn et al. 2002, 2004a, Taylor 2004, Wiles 2004). Unfortunately, despite much study since the early 1970s and great advances in knowledge of the species, researchers remain unsure which threats are most significant to the region's whales. Three primary factors are discussed in this section: reductions in prey availability, environmental contaminants, and vessel effects. None have yet been directly tied to the recent decline of the southern resident population (Krahn et al. 2002), but continued research should provide further insight into relationships. Perhaps most likely, two or more of these factors may be acting together to harm the whales (e.g., Sih et al. 2004). An example of how cumulative effects of multiple factors might be affecting whales would be vessel effects when combined with the stresses of reduced prey availability or increased contaminant loads (Williams et al. 2002a). Under such a scenario, reduced foraging success resulting from effects of vessels and declining salmon abundance may lead to chronic energy imbalances and poorer reproductive success, or all three factors may work to lower an animal's ability to suppress disease.

Reduction of Prey Populations

Healthy killer whale populations are dependent on adequate prey levels. Reductions in prey availability may force whales to spend more time foraging and might lead to reduced reproductive rates and higher mortality rates. Human influences have had profound impacts on the abundance of many prey species in the northeastern Pacific during the past 150 years. Foremost among these, many stocks of salmon have declined significantly due to overfishing and degradation of freshwater and estuarine habitats through urbanization, dam building, and forestry, agricultural, and mining practices (National Research Council 1996, Slaney et al. 1996, Gregory and Bisson 1997, Lichatowich 1999, Lackey 2003, Pess et al. 2003, Schoonmker et al. 2003). Populations of some other known or potential prey species, such as marine mammals and various fish, have similarly declined or fluctuated greatly through time. Status assessments of the food resources available to killer whales in the region are complicated by numerous considerations, including a lack of detailed knowledge on the food habits and seasonal ranges of the whales, uncertainties in the historical and current abundance levels of many localized populations of prey, and the cyclic nature of large-scale changes in ocean conditions.

Information on the diets of resident killer whales in Washington and British Columbia is very limited, but it is generally agreed that salmon are the principal prey in spring, summer, and fall (Heimlich-Boran 1986, Felleman et al. 1991, Ford et al. 1998). Current data suggest that chinook salmon, the region's largest salmonid, are the most commonly targeted prey species

(Ford et al. 1998). Other salmonids appear to be eaten less frequently, as are some non-salmonids such as rockfish, halibut, lingcod, and herring. Unfortunately, conclusions about resident diets are limited by a number of observational biases (Ford et al. 1998, Baird 2000). Most information originates from a single published study (Ford et al. 1998) that focused on the northern residents from late spring to early fall. Few feeding data exist for the winter months for either resident population or for whales found away from inland waters. There has also been a reliance on surface feeding observations, which may underrepresent predation on bottom fish or other species. Further complicating an adequate understanding of whale-prey relationships is the possibility of dietary differences among pods and between sexes (Nichol and Shackleton 1996, Ford et al. 1998, Baird 2000).

Another poorly understood facet of diet is the extent to which resident killer whales have depended on specific salmon runs, both in the past and currently (Krahn et al. 2002). Several researchers have compared southern resident distribution with salmon sport catch records, but none have attempted to identify targeted runs. The population's annual presence in the vicinity of the San Juan Islands and Fraser River mouth from late spring to early fall suggests a dependence on salmon returning to this river system (Osborne 1999). This hypothesis is reasonable given the river's immense production of salmon (Northcote and Atagi 1997) and that its sockeye and pink runs pass through Haro Strait and surrounding waters. Heimlich-Boran (1986) correlated killer whale occurrence with salmon sport catch in the San Juan Islands and portions of Puget Sound, but did not describe the species or runs selected. Felleman et al. (1991) added that some small-scale winter occurrences of the whales were related to the presence of juvenile chinook, adult steelhead, and adult cutthroat trout (*Salmo clarkii*). Autumn movements of southern resident pods into Puget Sound roughly correspond with chum and chinook salmon runs (Osborne 1999), as illustrated by the presence of whales in Dyes Inlet during a strong run of chum in 1997. Both California sightings and one off Westport, Washington, have coincided with large runs of chinook salmon (K. C. Balcomb, unpubl. data; M. B. Hanson, pers. obs., in Krahn et al. 2004a). Northern resident occurrence in Johnstone Strait has been tied more strongly to the large seasonal runs of sockeye and pink salmon, as well as chum salmon to a lesser extent (Nichol and Shackleton 1996).

Without better knowledge of selected salmon runs, the effects on resident killer whales of changing salmon abundance in key runs cannot be judged. In former times, the whales may have simply moved to other areas with adequate food or shifted their diets to alternate fish stocks in response to the reduction of a heavily used run (Ford et al. 2000). These options may be less viable now due to broader declines of various fish populations in the region.

As already noted, there is an absence of comprehensive and accurate estimates of salmon abundance for significant portions of the ranges of southern and northern residents. In many cases, salmon population estimates from the 1800s to mid-1900s are crude or non-existent. Furthermore, estimates originate from a variety of sources and methods (i.e., catch data, escapement, or both) and therefore may not be comparable among or within locations (Bisson et al. 1992). Some include both wild and hatchery fish, whereas others tallied only one of these groups. Substantial interannual variability is also inherent in many stocks. Finally, concise summaries of specific run size information can be dauntingly difficult to locate within fisheries agency records. Despite these limitations, some general trends are apparent. Of greatest significance are the overall major reductions in the natural breeding populations of most species between the 1800s to mid-1900s (Table 4). Many runs have continued to decrease since then, but others have partially recovered. Declines are particularly prevalent in Washington, Oregon, Idaho, California, and southern British Columbia due to greater human impacts on freshwater and estuarine habitats as well as ocean productivity cycles, whereas populations in Alaska have been little affected (Riddell 1993, Slaney et al. 1996, Nehlsen 1997, Wertheimer 1997, Yoshiyama et al. 1998, Kope and Wainwright 1998, Lackey 2003, Schoonmaker et al. 2003). Among naturally spawning salmon, 30 of the 49 evolutionarily significant population units (ESUs) in the western contiguous U.S. are currently listed as threatened (22 ESUs), endangered (4), or candidates for listing (4) under the federal Endangered Species Act. Half or more of all chinook, steelhead, and chum ESUs are listed. Some of the remaining 19 ESUs are predicted to become endangered unless specific recovery actions can be accomplished. Despite this overall pattern, an assessment of natural salmon stocks in Washington during the late 1980s and early 1990s found that of 309 stocks with sufficient data to assess current status, 60.5% were in fact healthy and 39.5% were depressed or of critical status (WDF et al. 1993). A disproportionately greater number of healthy stocks were located in Puget Sound, whereas more depressed and critical stocks occurred in the Columbia River basin.

Many wild salmon runs have been supplemented by significant numbers of hatchery-reared salmon since the 1950s and 1960s, when modern hatchery programs began being widely implemented (Mahnken et al. 1998). In Washington, hatchery fish now account for about 75% of all chinook and coho salmon and nearly 90% of all steelhead harvested. In Puget Sound and the Strait of Georgia, the amounts of artificially reared salmon are variable with species, but significant numbers of hatchery chinook and coho are present in many runs (e.g., Sweeting et al. 2003). The extent that resident whales consume hatchery salmon is poorly understood, but hatchery fish are known to be consumed (J. K. B. Ford, unpubl. data) and may represent an important part of the diet for southern residents.

For southern resident killer whales, salmon population levels are particularly crucial in and around the Georgia Basin and Puget Sound, which are the core area for these whales during much of the year. Overall salmon abundance in Puget Sound has been roughly stable or increasing for the past several decades, due largely to the strong performance of pink and chum salmon. Both species have been at or near historic levels of abundance for the past 20-25 years (Hard et al. 1996; Johnson et al. 1997; WDFW 2004; J. Ames, unpubl. data). No recent changes in salmon populations are obviously apparent that may be responsible for the decline of L pod.

Population trends of salmon stocks in the range of southern resident killer whales are summarized below, along with those of several other known prey species. Brief discussions of additional factors affecting salmon abundance and productivity are also presented. Detailed accounts of the life history of Pacific salmon can be found in Groot and Margolis (1991), with summaries of occurrence in Washington presented in Wydoski and Whitney (2003).

Table 4. Summary of historical and recent estimates of salmon numbers (in thousands) produced by western North American river systems between the Strait of Georgia and central California[a].

		Species					
Region	Period of time	Chinook	Pink	Coho	Chum	Sockeye	Steelhead
Fraser River	Late 1800s to mid-1900s	750[b]	23,850[b]	1,230[b]	800[b]	925-40,200[c]	nd
	Mid-1900s to early 1980s	150[b]	1,900-18,700[d]	160[b]	390[b]	967-18,800[c]	nd
	Mid-1980s to early 1990s	140-280[e]	7,200-22,180[d]	40-100[b]	ca 1,300[f]	3,770-22,000[c]	nd
	Early 1990s to current	140-350[e]	3,600-21,200[d]	increasing[f]	13× greater since 1997[f]	3,640-23,600[c]	12[g]
Puget Sound	Late 1800s to early 1900s	250-700[h]	1,000-16,000[h]	700-2,200[h]	500-1,700[h]	1,000-22,000[h]	nd
	Mid-1900s	40-100[h]	350-1,000[i]	200-600[h]	300-600[i]	150-400[i]	nd
	Mid-1980s to early 1990s	80-140[i]	1,000-1,930[j]	300-800[i]	1,040-2,030[k]	92-622[j]	>41[l]
	Early 1990s to current	118-280[m]	440-3,550[i]	200-500[h]	570-3,390[j]	37-555[i]	nd
Coastal Washington	Mid- to late 1800s	190[n]	nd	nd	nd	Nd	nd
	Mid-1900s	nd	nd	nd	80-100[i]	20-130[i]	nd
	Mid-1980s to early 1990s	30-115[i]	nd	40-130[i]	10-325[i]	15-80[i]	25-50[i]
	Early 1990s to current	50-65[i]	nd	30-70[i]	60-175[i]	20-80[i]	30-40[i]
Columbia River	Mid- to late 1800s	4,800-9,200[o]	nd	900-1,780[o]	540-1,390[o]	2,600-2,840[o]	570-1,350[o]
	Mid-1900s	564-1,412[p]	nd	21-786[p]	1-426[p]	11-335[p]	252-438[p]
	Mid-1980s to early 1990s	483-1,237[p]	nd	262-1,575[p]	1-5[p]	47-200[p]	292-559[p]
	Early 1990s to current	382-642[p]	nd	89-624[p]	1-5[p]	9-94[p]	240-428[p]
Mid- to northern coastal Oregon	1900	300-600[q]	nd	1,700[q]	nd		nd
	Mid-1900s	nd	nd	nd	130[r]		nd
	Mid-1980s to early 1990s	115-420[q,s]	nd	70[q]	29[r]		>178[l]
	Early 1990s to current	nd	nd	nd	nd		nd
Northern coastal California	Mid- to late 1800s	300[n]	nd	1,200[t]	nd		nd
	Mid-1900s	256[t]	nd	200-500[u]	nd		nd
	Mid-1980s to early 1990s	nd	nd	13[u]	nd		nd
	Early 1990s to current	ca 10-50[v]	nd	nd	nd		nd
Central Valley, California	Mid- to late 1800s	1,000-2,000[w]	nd	nd	nd		nd
	Mid-1900s	117->612[w]	nd	nd	nd		nd
	Mid-1980s to early 1990s	137-387[w]	nd	nd	nd		nd
	Early 1990s to current	125->415[w]	nd	nd	nd		>12[l]

[a] Estimates may represent catch data, escapement, or estimated run size, and therefore may not be comparable between or within sites. Some estimates include hatchery fish. Early catch records for sockeye and pink salmon in Puget Sound are especially problematic because they include Fraser River salmon caught by American fishermen and landed in Puget Sound ports (J. Ames, pers. comm.). Periods without data for particular species are represented by “nd.”

[b] Northcote and Atagi (1997), catch and escapement; [c] I. Guthrie (unpubl. data); [d] B. White (unpubl. data); [e] DFO (1999), catch and escapement; [f] DFO (2001); [g] Simon Fraser University (1998); [h] Bledsoe et al. (1989), catch only; [i] Johnson et al. (1997b), wild run sizes only; [j] J. Ames (unpubl. data); [k] WDFW (2004); [l] Busby et al. (1996); [m] B. Sanford (unpubl. data), adult run size only, including both wild and hatchery fish, but excluding spring chinook; [n] Myers et al. (1998); [o] Northwest Power Planning Council (1986); [p] WDFW and ODFW (2002); [q] Kostow (1997); [r] Nickelson et al. (1992); [s] Nicholas and Hankin (1989); [t] California Department of Fish and Game (1965); [u] Brown et al. (1994); [v] Mills et al. (1997); [w] Yoshiyama et al. (1998).

Chinook salmon. Chinook are the least common species of salmon in the northeastern Pacific (Wydoski and Whitney 2003, Riddell 2004). Long- and short-term trends in the abundance of wild stocks are predominantly downward, with some populations exhibiting severe recent declines (Table 4). However, total abundance in Puget Sound, the eastern Strait of Juan de Fuca, and the lower Columbia River basin has been relatively high in recent decades due to production from hatcheries (Myers et al. 1998; B. Sanford, pers. comm.). All spring-run populations in these areas are depressed and most are likely to become endangered in the foreseeable future. Many of the formerly vast populations in the mid- to upper Columbia and Snake River basins have declined considerably or virtually disappeared, although some (e.g., fall runs in the upper Columbia) remain moderately large (WDF et al. 1993, Myers et al. 1998, WDFW and ODFW 2002). Total abundance along the Washington and Oregon coasts is relatively high and long-term population trends are generally upward, but a number of runs are experiencing severe recent declines. In British Columbia, chinook escapements were higher in the 1990s than at any other time dating back to the 1950s, but concern remains over the depressed status of stocks in southern British Columbia (Slaney et al. 1996, Northcote and Atagi 1997, Henderson and Graham 1998, Riddell 2004). The status of stocks from southern Oregon to California's Central Valley is variable, with a number of runs in poor condition or extirpated (Yoshiyama et al. 2000). Others (e.g., Rogue River, fall runs in the upper Klamath and Trinity Rivers and the Central Valley) remain fairly abundant, although hatchery fish tend to be a large component of escapements (Myers et al. 1998, Yoshiyama et al. 2000).

Pink salmon. Pink salmon are the most abundant species of Pacific salmon (Wydoski and Whitney (2003) and reach the southern limit of their primary spawning range in Puget Sound. Most odd-year populations in the sound and southern British Columbia appear healthy and current overall abundance is close to historical levels or increasing (Hard et al. 1996; Northcote and Atagi 1997; J. Ames, pers. comm.), whereas even-year runs are naturally small. Numbers in Puget Sound have been high (mean odd year run size = 1.47 million fish, range = 440,000-7.4 million) in most years since at least 1959 (J. Ames, unpubl. data). However, several populations along the Strait of Juan de Fuca and in Hood Canal are declining or possibly extinct. Considerable variation in run size can occur, as seen in the Fraser River, where odd-year runs varied from about 3.6 to 22.2 million between 1991 and 2001 (B. White, unpubl. data). Stocks in Puget Sound and British Columbia are comprised almost entirely of naturally spawning fish.

Coho salmon. Abundance south of Alaska has declined despite the establishment of large hatchery programs (Kope and Wainwright 1998). A number of risk factors, including widespread artificial propagation, high harvest rates, extensive habitat degradation, a recent dramatic decline in adult size, and unfavorable ocean conditions, suggest that many wild stocks may encounter future problems (Weitkamp et al. 1995). Populations supplemented with large numbers of hatchery fish are considered near historical levels in Puget Sound and the Strait of Georgia, with overall trends considered stable (Weitkamp et al. 1995). Natural coho populations in British Columbia have been in decline since the 1960s (Slaney et al. 1996, Northcote and Atagi 1997, Henderson and Graham 1998, Sweeting et al. 2003, Riddell 2004), while those in the lower Columbia River basin and along the coasts of Oregon and northern California are in poor condition (Weitkamp et al. 1995). Most coho in the Stait of Georgia and Columbia basin originate from hatcheries.

Chum salmon. Chum salmon are abundant and widely distributed in Puget Sound and the Strait of Georgia, and currently comprise the majority of wild salmon in many river systems. Autumn runs are prevalent in both areas. Recent numbers in Puget Sound are at or near historic levels (Table 4), fluctuating between about 0.6 and 2.6 million fish (including hatchery fish) from the early 1980s to 1998 (WDFW 2004). Numbers dropped to fewer than 700,000 fish in 1999 and 2000 due to unfavorable ocean conditions, but rebounded strongly in 2001 and 2002, with run size estimated at nearly 3.4 million fish in 2002 (WDFW 2002, 2004). Hatchery fish comprise 19-47% of the total population in any given year. Although chum abundance in British Columbia is characterized by large annual fluctuations, overall escapements have been slowly increasing since the 1950s (Henderson and Graham 1998). However, numbers remain lower than those observed in the early 1900s (Henderson and Graham 1998). The Columbia River once supported commercial landings of hundreds of thousands of chum salmon, but returning numbers fell drastically in the mid-1950s and never exceeded 5,000 fish per year in the 1990s (WDFW and ODFW 2002). Stock sizes are variable along the Washington coast, but are low relative to historic levels on the Oregon coast.

Sockeye salmon. Sockeye are the second most common species of salmon in the northeastern Pacific, with spawning populations usually associated with lakes for the rearing of juveniles (Wydoski and Whitney 2003). Only three of Washington’s nine sockeye salmon populations are considered healthy (WDF et al. 1993) and many are naturally small (Gustafson et al. 1997). Declines are especially noticeable in the Columbia basin (Table 4; WDFW and ODFW 2002). From 1993-2002, run size of the introduced stock in the Lake Washington system averaged 230,000 fish (range = 35,000-548,000) (J. Ames, unpubl. data). Sockeye numbers have been recovering in British Columbia since the 1920s (Northcote and Atagi 1997, Henderson and Graham 1998). The Fraser River holds the largest run, usually accounting for more than half of all sockeye production in the province. Huge runs occur cyclically every four years in the river and elsewhere in southern British Columbia, which may have a substantial effect on annual food availability for southern resident killer whales. Between 1990 and 2002, run sizes varied from about 3.6 to 23.6 million fish (I. Guthrie, unpubl. data).

Steelhead. More than half of the assessed wild populations in Washington are considered depressed (WDF et al. 1993) and many are declining (Busby et al. 1996). However, stocks throughout the state are heavily supplemented with hatchery fish. Populations are largest in the Columbia River basin (Table 4), where summer runs have generally increased since the 1970s and winter runs have declined (WDFW and ODFW 2002). Wild coastal steelhead populations are considered healthy in Washington (WDFW 2002), but are largely in decline in Oregon and northern California (Busby et al. 1996).

Hatchery production. Hatchery production has partially compensated for declines in many wild salmon populations and therefore has likely benefited resident killer whales to some undetermined extent. However, hatcheries are also commonly identified as one of the factors responsible for the depletion of wild salmon stocks (Sweeting et al. 2003, Gardner et al. 2004).

This can occur through a number of processes. Probably the most important of these is through mixed stock fishing, wherein wild fish are harvested unsustainably when they co-occur with large numbers of hatchery fish (Gardner et al. 2004). Physical and genetic interactions between wild and hatchery salmon can weaken wild stocks by increasing the presence of deleterious genes (Reisenbichler 1997, Reisenbichler and Rubin 1999). Substantial genetic ingress can occur in native salmon populations, as demonstrated by wild spawning coho salmon in the lower Nooksack and Samish Rivers of Washington, which are now genetically similar to the hatchery fish also present (Small et al. 2004). Competition for food and other resources between hatchery and wild fish may reduce the number of wild fish that can be sustained by the habitat (Flagg et al. 1995, Levin et al. 2001). Predation by hatchery fish and transfer of disease are other mechanisms in which wild populations may be harmed (Gardner et al. 2004). Lastly, hatchery policies that encourage longer residency periods in Puget Sound salmon, especially chinook salmon, may result in substantially higher PCB contamination of the fish (S. M. O'Neill, unpubl. data).

Salmon size. Many North Pacific populations of five salmon species have declined in physical size during the past few decades (Bigler et al. 1996). For example, mean weights of adult chinook and coho salmon from Puget Sound have fallen by about 30% and 50%, respectively (Weitkamp et al. 1995; Quinn et al. 2001; B. Sanford, pers. comm.). In the Columbia River, chinook weighing 50-60 lb were once a small but regular component of runs, but are now a rarity. Decreases in mean weights have also been reported for adult chum (11-40%), pink (20%), and sockeye (6%) salmon (Schoonmaker et al. 2003). Size reductions have been linked to abundance levels and ocean condition (Bigler et al. 1996, Pyper and Peterman 1999), but other factors such as harvest practices, genetic changes, effects of fish culture, and density-dependent effects in freshwater environments attributable to large numbers of hatchery releases may also play a role (Weitkamp et al. 1995). Heavy fishing pressure often produces younger age distributions in populations, resulting in fewer salmon maturing in older age classes and a smaller overall average adult size (Pess et al. 2003; J. Ames, pers. comm.). Hatcheries also have a tendency to produce returning adults that are younger and smaller (B. Sanford, pers. comm.). Reduced body size not only poses a number of risks to natural salmon populations, but may also impact killer whales and other predators. Smaller fish may influence the foraging effectiveness of killer whales by reducing their caloric intake per unit of foraging effort, thus making foraging more costly. A combination of smaller body sizes and declines in many stocks means an even greater reduction in the biomass of salmon resources available to killer whales. Recent mean weights of adult ocean salmon, including both wild and hatchery fish, are as follows: chinook, 3.3-8.3 kg; chum, 3.3-4.8 kg; coho, 1.8-3.2 kg; sockeye, 2.6 kg; and pink, 1.5 kg (Schoonmaker et al. 2003).

Salmon body composition. Energy value and possibly nutritional quality differ among salmon species. Osborne (1999) reported the caloric content of five Pacific salmon species as follows: chinook, 2,220 kcal/kg; sockeye, 1,710 kcal/kg; coho, 1,530 kcal/kg; chum, 1,390 kcal/kg; and pink, 1,190 kcal/kg. Thus, prey switching from a preferred but declining salmon species to a more abundant alternate species may result in lowered energy intake for resident killer whales. Additionally, chinook salmon are unique in that spring run fish generally have greater fat concentrations than fall run fish (B. Sanford, pers. comm.). This is due to differences in life history strategies, with spring chinook needing larger amounts of fat for swimming to spawning sites located farther upstream and to survive their longer residency period in rivers prior to spawning. This means that population reductions in spring chinook (see Seasonal Availability) may result in the scarcity of a preferred and valuable food item for killer whales.

Salmon distribution. Habitat alteration, hatchery and harvest practices, and natural events have combined to change regional and local patterns of salmon distributions during the past 150 years, but especially since about 1950 (Bledsoe et al. 1989, Nehlsen 1997). Some historically productive populations are no longer large, whereas other runs may have increased in abundance through hatchery production. Limited evidence indicates that hatcheries do not greatly change the pelagic distribution of coho salmon (Weitkamp et al. 1995), but they can strongly influence the nearshore presence of salmon and thus the availability of salmon for predators (Krahn et al. 2002). Within Puget Sound and the Strait of Georgia, it is unknown whether changes in salmon distribution have accompanied long-term changes in abundance. However, salmon distribution is believed to have remained consistent in this region since at least the 1960s. In particular, pink and chum salmon currently occupy nearly all of the habitat that would have been available historically (J. Ames, pers. comm.).

Perhaps the single greatest change in food availability for resident killer whales since the late 1800s has been the decline of salmon in the Columbia River basin. Estimates of predevelopment run size vary from 10-16 million fish (Table 4; Northwest Power Planning Council 1986) and 7-30 million fish (Williams et al. 1999), with chinook salmon being the predominant species present. Since 1938, annual runs have totaled just 750,000 to 3.2 million fish (WDFW and ODFW 2002). Returns during the 1990s averaged only 1.1 million salmon, representing a decline of 90% or more from historical levels. With so many fish once present, salmon returning to the Columbia River mouth may have been an important part of the diet of southern resident whales.

Similarly, California's Central Valley once supported large numbers of Pacific salmon, but many runs are now severely diminished or gone entirely (Table 4; Yoshiyama et al. 1998, 2000). Chinook salmon were the primary salmonid in this basin as well. Appreciable numbers of chinook from the Central Valley are known to have migrated northward to Oregon, Washington, and British Columbia (Yoshiyama et al. 1998), and therefore may have been a significant dietary item for the southern residents.

Seasonal availability. Even though salmon are currently considered relatively numerous in a number of areas (when hatchery fish are included), patterns of seasonal availability differs from historical patterns in some instances. Thus, resident killer whales may have lost some seasonally important sources of prey, while perhaps gaining others, as seen in the examples that follow. Natural salmon runs throughout the region have always been greatest from August to December, but there may have been more spring and summer runs in the past (J. Ames, pers. comm.). In particular, spring and summer chinook salmon were abundant in the Columbia River until about the late 1800s (Lichatowich 1999). Populations of spring chinook have also declined severely in Puget Sound, with most chinook runs now dominated by later-timed fish, which return to rivers in late summer and fall (B. Sanford, pers. comm.). This problem may be partially offset by the relatively recent presence of "blackmouth" salmon, which are a hatchery-derived form of chinook that tend to reside year-round in Puget Sound. Through deliberate management programs, these fish have been present in large enough numbers to support a recreational fishing season since the 1970s. Contractions in run timing can also affect food availability for killer whales, as seen in several Washington populations of hatchery coho salmon, where return timing was condensed from about 14 weeks to 8 weeks during a 14-year period even though total fish numbers remained about the same (Flagg et al. 1995).

Climatic variability. A naturally occurring climatic pattern known as the Pacific Decadal Oscillation has recently been identified as a major cause of changing marine productivity and salmon abundance in the North Pacific (Mantua et al. 1997, Francis et al. 1998, Beamish et al. 1999, Hare et al. 1999, Benson and Trites 2002). The system is characterized by alternating 20-30-year shifts in ocean temperatures across the region, which produced cooler water temperatures from 1890-1924 and 1947-1976 and warmer water temperatures from 1925-1946 and 1977 to at least 2001. Cooler periods promote coastal biological productivity off the western contiguous U.S. and British Columbia, but inhibit productivity in Alaska, whereas warmer phases have the opposite effect (Hare et al. 1999). Salmon are probably most affected through changes in food availability and survival at sea (Benson and Trites 2002), but associated terrestrial weather patterns may also be a factor. Higher rainfall at certain times of the year during warm regimes can cause greater stream flow and flooding in western Washington, thereby reducing salmon egg survival (J. Ames, pers. comm.). The most recent warm period has been strongly tied to lower salmon production south of Alaska (Hare et al. 1999). Greater salmon numbers in Washington during the past several years indicate that the latest warm phase has concluded. Evidence suggests that the Pacific Decadal Oscillation has existed for centuries, which implies that sizable fluctuations in salmon abundance are a natural phenomenon in the North Pacific (Beamish et al. 1999, Benson and Trites 2002).

On shorter time scales, El Niño and La Niña events may also influence Pacific salmon populations, either beneficially or detrimentally, depending on salmon species, stock, and geographic range.

Although not necessarily related to the to the climate patterns described above, changes in ocean temperature also directly influence salmon abundance in the Strait of Juan de Fuca and the vicinity of the San Juan Islands. In years when ocean conditions are cooler than usual, the majority of sockeye salmon returning to the Fraser River do so via this route, but when warmer conditions prevail, migration is primarily through Johnstone Strait (Groot and Quinn 1987).

Aquaculture of Atlantic salmon. The intensive commercial farming of Atlantic salmon (*Salmo salar*) and smaller amounts of chinook and coho salmon in marine netpens in British Columbia and Washington represents an additional potential, but highly debated, threat to wild Pacific salmon (Gallaugher and Orr 2000, Gardner and Peterson 2003). The region's industry has grown dramatically in the past several decades and produces an estimated 50 million kg of salmon annually, about 90% of which comes from British Columbia (Amos and Appleby 1999). Licensed net-pen operations currently occur at about 126 sites in British Columbia and eight sites in Washington (A. Thomson, pers. comm.; J. Kerwin, pers. comm.). Concerns center primarily over 1) marine netpenned Atlantic salmon transmitting infectious diseases to adjoining wild salmon populations and 2) escaped Atlantic salmon becoming established in the wild and competing with, preying on, or interbreeding with wild Pacific salmon. Current evidence suggests that these concerns are largely unfounded in Washington and that Atlantic salmon aquaculture poses minimal risk to wild salmon stocks there (Nash 2001, Waknitz et al. 2002; J. Kerwin, pers. comm.). Escapes of penned Atlantic salmon exceeded 100,000 fish per year in the late 1990s in Washington (Amos and Appleby 1999), but improved management of salmon farms since then has greatly reduced this problem, resulting in far fewer free-ranging Atlantic salmon in the state's waters (WDFW 2003). The situation in British Columbia is far more uncertain because of the much larger size of the industry (Gardner and Peterson 2003), which has resulted in larger numbers of escapes (mean = 47,150 fish per year from 1994-2002) and regular capture of free-ranging fish (mean = 1,713 fish reported per year from 1992-2002) (DFO 2003). Small numbers of naturally produced juvenile Atlantic salmon have been recorded in three rivers on Vancouver Island (e.g., Volpe 2000), but self-sustaining populations are not known to occur anywhere in the province (A. Thomson, pers. comm.). However, limitations in stream monitoring make it difficult to rule out the absence of additional populations (Gardner and Peterson 2003). There is compelling evidence that sea lice (*Lepeophtheirus salmonis*) are transmitted from salmon farms to wild salmon, but the severity of impacts to wild fish is unknown (Gardner and Peterson 2003). Sea lice from farms have been linked to a decline of wild pink salmon populations in British Columbia's Broughton Archipelago (Morton et al. 2004), although this finding has been disputed and may simply reflect a normal downward fluctuation in the populations. Salmon farms in British Columbia are concentrated along the central coast and on west-central Vancouver Island, and are projected to continue expanding in number in the future. The eight farms in Washington are located at Ediz Hook (Clallam County), Cypress and Hope Islands (Skagit County), and off southern Bainbridge Island (Kitsap County).

Other fish species. Declines in abundance have also been recorded in some of the other known prey of resident killer whales. The Pacific herring stock in the Georgia Basin and Puget Sound collapsed from overharvesting in the 1960s, but recovered to high levels by the late 1970s through better management practices (DFO 2002a). However, some subpopulations, such as those at Cherry Point and Discovery Bay in Puget Sound, have fallen so low that they may now be threatened (Stout et al. 2001, National Marine Fisheries Service 2004c). Herring abundance has also decreased off western Vancouver Island since 1989, probably because of warm ocean temperatures (DFO 2001). Heavy fishing pressure was responsible for decreases in lingcod populations throughout British Columbia during the 1970s (DFO 2002b). Numbers generally responded to improved management and rebounded during the 1980s and early 1990s, but have again declined in subsequent years. Abundance has remained low in the Strait of Georgia since the 1980s. Excessive exploitation has also caused rockfish stocks to plummet along much of the Pacific coast in recent decades (Bloeser 1999, Love et al. 2002). Copper, brown, and quillback rockfishes are among the most affected species in Puget Sound. In contrast to the species mentioned above, catch data suggest significant growth in Pacific halibut populations in British Columbia and Washington from the mid-1970s to late 1990s (International Pacific Halibut Commission 2002). Considerable fluctuation in total groundfish biomass was observed in Puget Sound and the southern Georgia Strait from 1987 to 2001 (Palsson et al. 2004).

Prey availability summary. Resident killer whales have likely been exposed to natural changes in the availability of salmon and some other prey for millennia. During the past century and a half, human harvest pressures and alterations to the environment have undoubtedly caused important changes in food availability for resident whales. Due to a lack of information on many topics, especially which species runs are important, it is unknown whether current fish stocks are a limiting factor for either population of resident whales. Favorable ocean conditions across the region in the next decade or two may temporarily alleviate possible food limitations by boosting overall salmon numbers. Nevertheless, the long-term prognosis for salmon recovery in the region is unclear. Improved management programs will undoubtedly benefit some salmon populations, but continued human population growth and urbanization will place greater pressure on freshwater and marine ecosystems and challenge the efforts of managers seeking to achieve meaningful recovery (Langer et al. 2000).

Environmental Contaminants

Recent decades have brought rising concern over the adverse environmental effects resulting from the use and disposal of numerous chemical compounds in industry, agriculture, households, and medical treatment. Many types of chemicals are toxic when present in high concentrations, including legacy compounds such as organochlorines, polycyclic aromatic hydrocarbons (PAHs), and heavy metals that have long been recognized as problematic. However, a growing list of so-called “emerging” contaminants and other pollutants, such as brominated flame retardants (BFRs), perfluorinated compounds, and numerous other substances, are increasingly being linked to harmful biological impacts as well. Contaminant classes vary in their chemical properties and structures, persistence in the environment, pathways of transport through ecosystems, and effects on marine mammals and other wildlife. Despite their toxicity, most of these chemicals are still being manufactured or used in many countries.

Organochlorines. Organochlorines are frequently considered to pose the greatest risk to killer whales (Ross et al. 2000a, Center for Biological Diversity 2001, Krahn et al. 2002) and comprise a diverse group of chemicals manufactured for industrial and agricultural purposes, such as polychlorinated biphenyls (PCBs), DDT, and certain other pesticides, or produced as unintentional by-products during industrial and combustion processes, such as the dioxins (PCDDs) and furans (PCDFs). Many organochlorines are highly fat soluble (lipophilic) and have poor water solubility, which allows them to accumulate in the fatty tissues of animals, where the vast majority of storage occurs (O’Shea 1999, Reijnders and Aguilar 2002). Some are highly persistent in the environment and resistant to metabolic degradation. Vast amounts have been produced and released into the environment since the 1920s and 1930s. The persistent qualities of organochlorines mean that many are ultimately transported to the oceans, where they enter marine food chains. Bioaccumulation through trophic transfer allows relatively high concentrations of these compounds to build up in top-level marine predators, such as marine mammals (O’Shea 1999). The toxicity of several organochlorines has led to bans or restrictions on their manufacture and use in northern industrial countries (Barrie et al. 1992). Most agriculture uses of DDT ended in the U.S. in 1972 and in Canada from 1970-1978. Production of PCBs stopped in the U.S. in 1977 and importation into Canada was prohibited in 1980.

However, these compounds continue to be used widely in other parts of the world, including Asia and Latin America. Organochlorines enter the marine environment through several sources, such as atmospheric transport, ocean current transport, and terrestrial runoff (Iwata et al. 1993, Grant and Ross 2002, Garrett 2004, Hartwell 2004). As a result, these compounds have become distributed throughout the world, including seemingly pristine areas of the Arctic and Antarctic (Barrie et al. 1992, Muir et al. 1992). Much of the organochlorine load in the northern Pacific Ocean originates through atmospheric transport from Asia (Barrie et al. 1992, Iwata et al. 1993, Tanabe et al. 1994).

Killer whales are candidates for accumulating high concentrations of organochlorines because of their position atop the food web and long life expectancy (Ylitalo et al. 2001, Grant and Ross 2002). Their exposure to these compounds occurs only through diet (P. S. Ross, pers. comm.). Mammal-eating populations appear to be especially vulnerable to accumulation of contaminants because of the higher trophic level of their prey, as compared to fish-eating populations (Ross et al. 2000a).

Several studies have examined contaminant levels in killer whales from the North Pacific (Table 6). It should be noted that variable sample quality, limited background information, and different analytical techniques make direct comparisons between study results difficult (Ross et al. 2000a, Ylitalo et al. 2001, Reijnders and Aguilar 2002, Krahn et al. 2004b). Organochlorine concentrations are also known to vary in relation to an animal's physiological condition (Aguilar et al. 1999). Most marine mammals lose weight during certain stages of their normal life cycles, such as breeding and migration, or from other stresses, including disease and reduced prey abundance and quality. The depletion of lipid reserves during periods of weight loss can therefore alter detected organochlorine concentrations, depending on whether a compound is redistributed to other body tissues or is retained in the blubber (O'Shea 1999). Perhaps most importantly, caution should be used when comparing contaminant levels between free-ranging presumably healthy whales and stranded individuals, which may have been in poor health before their deaths. Sick animals commonly burn off some of their blubber before stranding. Furthermore, stranded killer whales tend to be older individuals and therefore may be more contaminated (P. S. Ross, pers. comm.).

Ross et al. (2000a) described the organochlorine loads of killer whale populations occurring in British Columbia and Washington. Male transient whales were found to contain significantly higher levels of total PCBs (ΣPCBs hereafter) than southern resident males, whereas females from the two communities carried similar amounts (Table 6). Both populations had much higher ΣPCB concentrations than northern resident whales. A similar pattern exists in Alaska, where transients from the Gulf of Alaska and AT1 communities contained ΣPCB levels more than 15 times higher than residents from the sympatric Prince William Sound pods of the southern Alaska community (Ylitalo et al. 2001). Profiles of specific PCB congeners were similar among the three killer whale communities from British Columbia and Washington, with congeners 153, 138, 52, 101, 118, and 180 accounting for nearly 50% of ΣPCB load (Ross et al. 2000a). Recent results from a much broader sample of killer whale communities from the North Pacific suggest that all transient populations and the southern residents possess high ΣPCB levels, whereas other resident populations and offshore whales have lower levels (G. M. Ylitalo et al., unpubl. data).

Relatively low amounts of ΣPCDDs and ΣPCDFs were detected in these whales, possibly because these compounds are more easily metabolized or excreted than many PCB congeners (Ross et al. 2000a). PCDD and PCDF levels detected in a small number of stranded whales from British Columbia and Washington also appear in Jarman et al. (1996). No detailed studies of ΣDDT concentrations in killer whales have been conducted to date in Washington or surrounding areas. However, preliminary evidence from stranded individuals in Oregon and Washington suggests that high levels of the metabolite *p,p'*-DDE may be present (Calambokidis et al. 1984, Hayteas and Duffield 2000). High concentrations of ΣDDTs, primarily *p,p'*-DDE, have also been detected in transient whales from Alaska (Ylitalo et al. 2001). Results from these studies establish the southern resident and transient populations of the northeastern Pacific as among the most chemically contaminated marine mammals in the world (Ross et al. 2000a, Ylitalo et al. 2001). This conclusion is further emphasized by the recent discovery of extremely high levels of ΣPCBs (about 1,000 mg/kg, wet weight) in a reproductively active adult female transient (CA189) that stranded and died on Dungeness Spit in January 2002 (G. M. Ylitalo, unpubl. data). While alive, this whale was recorded most frequently off California, thus its high contaminant load may largely reflect pollutant levels in prey from that region (M. M. Krahn, pers. comm.). It should be noted that organochlorine levels have not yet been established for the three southern resident pods. It is unknown whether L pod has higher contaminant levels than J or K pods, thus accounting for its recent decline.

Polychlorinated naphthalenes (PCNs) are another organochlorine group of concern. Evidence suggests that PCNs have the potential to bioaccumulate and exert "dioxin-like" toxicity (Rayne et al. 2004). PCNs most likely came from pulp mill discharges, with production ceasing in North America and Europe in the 1970s and 1980s. ΣPCN concentrations are relatively low in killer whales from the northeastern Pacific, with transients carrying the highest burdens, and much lower but similar levels occurring in southern and northern residents (Table 6; Rayne et al. 2004).

No direct temporal data are available to indicate whether contaminant concentrations have changed over time in the region's killer whales. Populations visiting Puget Sound have been exposed to PCBs and DDT for a number of decades. Sediment analyses indicate that large amounts of PCBs began entering marine ecosystems in the sound during the late 1930s, whereas inputs of DDT date back to the 1920s (Mearns 2001). The presence of both chemicals peaked in about 1960. Since then, environmental levels of many organochlorines (e.g., PCBs, dioxins, furans, organochlorine pesticides, and chlorophenols) have substantially declined (Gray and Tuominen 2001, Mearns 2001, Grant and Ross 2002). Mean ΣPCB concentrations in harbor seal pups from Puget Sound fell from more than 100 mg/kg, wet weight in 1972 to about 20 mg/kg, wet weight in 1990, but have since leveled off (Calambokidis et al. 1999). Recent modeling of PCB levels in killer whales from British Columbia and Washington suggests that concentrations have declined by about 2.5 times since 1970 (B. Hickie and P. S. Ross, unpubl. data).

Table 6. Contaminant concentrations (mean ± SE, mg/kg or µg/kg, lipid weight or wet weight) reported in tissue samples from killer whale populations in the North Pacific.

Reference	Population[a]	Age and sex[b]	Sample size[c]	Sample locations[d]	Sample years	ΣPCBs[e] (mg/kg)	ΣDDTs[e] (mg/kg)	*p,p'*-DDE[e] (mg/kg)	ΣPCNs[e] (µg/kg)	ΣPBDEs[e] (µg/kg)	ΣPBBs[e] (µg/kg)
Studies of free-ranging animals that were biopsied or otherwise tested[f]											
Ross et al. (2000a)	WCT	M	5	BC	1993-96	251 ± 55 (l)	-	-	-	-	-
	WCT	F	5	BC	1993-96	59 ± 21 (l)	-	-	-	-	-
	SR	M	4	BC	1993-96	146 ± 33 (l)	-	-	-	-	-
	SR	F	2	BC	1993-96	55 ± 19 (l)	-	-	-	-	-
	NR	AM	8	BC	1993-96	37 ± 6 (l)	-	-	-	-	-
	NR	AF	9	BC	1993-96	9 ± 3 (l)	-	-		-	-
Ylitalo et al. (2001)	AT	M, F	13	AK	1994-99	59 ± 12 (w)	83 ± 17 (w)	71 ± 15 (w)	-	-	-
	AT	M, F	13	AK	1994-99	230 ± 36 (l)	320 ± 58 (l)	280 ± 50 (l)	-	-	-
	SAR	M, F	64	AK	1994-99	3.9 ± 0.6 (w)	3.8 ± 0.6 (w)	3.1 ± 0.5 (w)	-	-	-
	SAR	M, F	64	AK	1994-99	14 ± 1.6 (l)	13 ± 1.8 (l)	11 ± 1.5 (l)	-	-	-
Rayne et al. (2004)	WCT	AM, JM	6	BC	1993-96	-	-	-	167 ± 131 (l)	1,105 ± 605 (l)	27 ± 13 (l)
	WCT	AF, JF	7	BC	1993-96	-	-	-	-	885 ± 706 (l)	-
	SR	AM, JM	5[g]	BC	1993-96	-	-	-	20 ± 15 (l)	942 ± 582 (l)	31± 9 (l)
	NR	AM, JM	13[g]	BC	1993-96	-	-	-	22 ± 7 (l)	203 ± 116 (l)	3.1 ± 1.1 (l)
	NR	AF, JF	8	BC	1993-96	-	-	-	-	415 ± 676 (l)	-
Ono et al. (1987)	U	AM	1	JA	1986	410 (w)	-	-	-	-	-
	U	AF	2	JA	1986	355 ± 5 (w)	-	-	-	-	-
Studies of stranded animals											
Calambokidis et al. (1984)	WCT	AM	1	BC	1979	250 (w)	-	640 (w)	-	-	-
	SR	AM	1	WA	1977	38 (w)	-	59 (w)	-	-	-
Jarman et al. (1996)	U	JM, AM, AF	6	BC, WA	1986-89	22 (w)	32 (w)	28 (w)	-	-	-
Hayteas and Duffield (2000)	U	JM	3	OR	1988-97	146 ± 135 (w)	-	174 ± 106 (w)	-	-	-
	U	AF	1	OR	1996	276 (w)	-	494 (w)	-	-	-
	U	JF	1	OR	1995	117 (w)	-	519 (w)	-	-	-

[a] WCT, west coast transients; SR, southern residents; NR, northern residents; AT, Gulf of Alaska and AT1 transients; SAR, southern Alaska residents; and U, not identified.

[b] M, males; F, females; A, adults; and J, juveniles.

[c] Number of animals sampled.

[d] BC, British Columbia; AK, Alaska; JA, Japan; WA, Washington; OR, Oregon.

[e] Concentrations expressed on the basis of lipid weight (l) or wet weight (w).

[f] The animals studied by Ono et al. (1987) were accidentally caught and killed by commercial fishermen.

[g] Smaller samples were tested for ΣPCNs and ΣPBBs.

Concentrations of most organochlorine residues in killer whales are strongly affected by an animal's age, sex, and reproductive status (Ross et al. 2000a, Ylitalo et al. 2001). Levels in juveniles of both sexes increase continuously until sexual maturity. Males continue to accumulate organochlorines throughout the remainder of their lives, but reproductive females sharply decrease their own burden by transferring much of it to their offspring during gestation and nursing. Because organochlorines are fat-soluble, they are readily mobilized from the female's blubber to her fat-rich milk and passed directly to her young in far greater amounts during lactation than through the placenta during pregnancy (Reijnders and Aguilar 2002). As a result, mothers possess much lower levels than their weaned offspring, as well as adult males of the same age bracket (Ylitalo et al. 2001). After females become reproductively senescent at about 40 years old, their organochlorine concentrations once again begin to increase (Ross et al. 2000a). Similar patterns of accumulation have been reported in other marine mammals (Tanabe et al. 1987, 1994, Aguilar and Borrell 1988, 1994a, Borrell et al. 1995, Beckmen et al. 1999, Krahn et al. 1999, Tilbury et al. 1999).

Birth order also influences the organochlorine burdens of killer whales. First-born adult male resident whales contain significantly higher levels of ΣPCBs and ΣDDTs than non-first-born males of the same age group (Ylitalo et al. 2001, Krahn et al. 2002). This pattern presumably exists among immature females as well. In other delphinids, females pass as much as 70-100% of their organochlorine load to their offspring during lactation, with the first calf receiving by far the largest burden (Tanabe 1988, Cockcroft et al. 1989, Borrell et al. 1995). Thus, females that have gone through previous lactation cycles carry substantially lower organochlorine loads and transfer reduced amounts to subsequent young (Aguilar and Borrell 1994a, Ridgway and Reddy 1995). These observations indicate that first-born killer whales are the most likely to suffer from any organochlorine toxicity effects (Ylitalo et al. 2001).

The effects of chronic exposure to moderate to high contaminant levels have not yet been ascertained in killer whales. There is no evidence to date that high organochlorine concentrations cause direct mortality in this species or other cetaceans (O'Shea and Aguilar 2001). However, a variety of more subtle physiological responses in marine mammals has been linked to organochlorine exposure (Table 7), including impaired reproduction (Béland et al. 1998, Reijnders 2003), immunotoxicity (Lahvis et al. 1995, de Swart et al. 1996, Ross et al. 1995, 1996a, 1996b, Jepson et al. 1999, Ross 2002, De Guise et al. 2003), hormonal dysfunction (Gregory and Cyr 2003), disruption of enzyme function and vitamin A physiology (Marsili et al. 1998, Simms et al. 2000), and skeletal deformities (Bergman et al. 1992). PCB-caused suppression of the immune system can increase susceptibility to infectious disease (Jepson et al. 1999, Ross 2002, Ross et al. 1996b) and was implicated in morbillivirus outbreaks that caused massive die-offs of dolphins in the Mediterranean Sea during the early 1990s (Aguilar and Borrell 1994b) and harbor seals and gray seals (*Halichoerus grypus*) in the North Sea in the late 1980s (de Swart et al. 1994, Ross et al. 1995, 1996a). Immune suppression may be especially likely during periods of stress and resulting weight loss, when stored organochlorines are released from the blubber and become redistributed to other tissues (Krahn et al. 2002). In captive bottlenose dolphins, females whose calves died before six months of age were found to have substantially higher levels of ΣDDTs and ΣPCBs than females with surviving calves

(Ridgeway et al. 1995). In non-marine mammals, PCB exposure has been commonly linked to hearing deficiencies, which result from thyroid hormone deprivation during early development (Colborn and Smolen 2003). This problem could have profound implications for cetaceans if it extends to this group.

Several studies have attempted to establish threshold levels at which organochlorines become toxic to marine mammals. However, susceptibility to PCBs varies substantially among mammal species, even within a genus, making it difficult to generalize about sensitivity (O'Shea 1999). Nevertheless, it is likely that all males from the three tested killer whale communities in Washington and British Columbia, as well as most female transients and southern residents, exceed the toxicity levels believed to cause health problems in other marine mammals (Ross et al. 2000a).

Brominated flame retardants. Polybrominated diphenyl ethers (PBDEs) have attracted recent concern because of their expanding presence in the environment, wildlife, and humans, and their lipophilic, bioaccumulative, and persistent qualities (de Wit 2002, Hall et al. 2003, Hites 2004). PBDEs are widely used as a flame retardant in consumer products and probably enter the environment via manufacturing processes and wastewater effluents. Production and use are especially high in North America, where contamination levels have been doubling about every four to six years during the past several decades (Hites 2004). PBDEs have been linked to endocrine disruption, immunotoxicity, neurotoxicity, and early developmental problems in laboratory animals and wild seals (de Wit 2002, Darnerud 2003, Hall et al. 2003). Rayne et al. (2004) documented PBDE concentrations in killer whales from the northeastern Pacific using biopsy samples collected from 1993-1996. Southern resident and transient whales carried similar ΣPBDE levels that were considerably higher than in northern residents (Table 6). No age- or sex-related differences in contamination were noted, although this may have been an artifact of the small sample size. Lindström et al. (1999) reported substantially higher PBDE levels in immature long-finned pilot whales (*Globicephala melas*) than in adults, suggesting that maternal transfer during lactation and gestation may occur. Rayne et al. (2004) found that BDE-47, BDE100, and BDE99 were the most prevalent congeners detected in killer whales from the northeastern Pacific. It is likely that substantial increases in the animals' ΣPBDE concentrations have occurred since the samples analyzed by Rayne et al. (2004) were collected, mirroring continuing widespread gains in the environment. Manufacture of two (penta-BDEs and octa-BDEs) of the three PBDE forms was terminated in the United States at the close of 2004.

Polybrominated biphenyls (PBBs) are a related type of flame retardant produced during the early 1970s. ΣPBB levels in resident and transient whales sampled from 1993 to 1996 were much lower than for ΣPBDEs (Table 6), but showed similar patterns of occurrence, with southern residents and transients having significantly higher concentrations than northern residents (Rayne et al. 2004).

Table 7. Summary of studies describing physiological effects resulting from exposure to different contaminants in marine mammals.

Effect	Type of contaminant	Species	Reference
Reduced resistance to disease and viruses	PCBs	Striped dolphin	Aquilar and Borrell (1994b)
Decreased lymphocyte response	PCBs, DDT	Bottlenose dolphin	Lahvis et al. (1995)
Decreased lymphocyte proliferation	Butylin compounds, non-ortho coplaner PCBs	Bottlenose dolphin, Dall's porpoise, California sea lion, spotted seal	Navata et al. (2002)
Disrupted immune function	PCBs	Harbor seal	de Swart et al. (1994), Ross et al. (1995)
Disrupted immune function	Non- and mono-ortho coplaner PCBs	Harbor seal pups, northern elephant seal pups	Shaw (1998)
Disrupted immune function, reduced T-cell function, reduced natural killer-cell function	Dioxin-like PCBs and furans	Harbor seal, grey seal	Ross et al. (2000)
Disrupted immune function, reduced T-cell response, reduced natural killer-cell function, increased polymorphonuclear granulocytes	PCBs, PCDDs, PCDFs, TCDD	Harbor seal	de Swart et al. (1989, 1993)
Adrenocorticol hyperplasia	Chlorinated hydrocarbons	Harbor porpoise	Kuiken et al. (1993)
Skin-oxidose activity	Organochlorines	Fin whale	Marsili et al. (1998)
Reduced vitamin A and thyroid hormone production	PCBs	Harbor seal	Brouwer et al. (1989)
Adrenal bioactivation and effects on thyroid metabolism	DDTs, PCBs	Gray seal	Lund (1994)
Reduced testosterone and immunoglobulin (pf IgG), suppression of antibody-mediated immunity, negative associations between PCBs and retinol and thyroid hormones in plasma	PCBs	Polar bear	Skaare et al. (2002)
Reduction of testosterone	Organochlorines	Polar bear	Oskam et al. (2001)
Variations in progesterone (P4) levels	Plasma sigma PCBs	Polar bear	Llaave et al. (2002)
Impaired reproduction	Organochlorines, DDT	Bottlenose dolphin	Reddy et al. (2001)
Impaired reproductive success in primiparous females	PCBs	Bottlenose dolphin	Schwacke et al. (2002)
Reproductive dysfunction	PCBs	Ringed seal	AMAP (1998)
Reproductive failure	PCBs	Harbor seal	Reijnders (1986)
Premature births	PCBs, DDT	California sea lion	Gilmartin et al. (1976)
Premature births	Organochlorines, DDT	California sea lion	Delong et al. (1973)
DNA strand breakage and repair	Methyl mercury chloride	Bottlenose dolphin	Taddei et al. (2001)

Other chemical compounds. With up to 1,000 new chemicals entering the global environment annually, it is difficult for environmental agencies to monitor levels and sources of all contaminants, and to provide effective regulation (Grant and Ross 2002). Studies are beginning to identify many relatively new substances as potentially harmful to marine organisms, including perfluorinated compounds, polychlorinated paraffins (PCPs), polychlorinated naphthalenes (PCNs), polychlorinated terphenyls (PCTs), endocrine disruptors (e.g., synthetic estrogens, steroids, some pesticides), pharmaceuticals, and personal care products (e.g., diagnostic agents and cosmetics) (Grant and Ross 2002). For example, perfluorooctane sulfonate (PFOS), a type of perfluorinated compound that is persistent and biomagnified, has been recently detected in a variety of marine mammals species from the northern hemisphere (Kannan et al. 2001, Van de Vijver et al. 2003). Endocrine disruptors may affect thyroid function, decrease fertility, feminize or masculinize genital anatomy, suppress immune function, and alter behavior (Yamamoto et al. 1996). The effects of all these compounds on killer whales remain unknown.

Toxic elements. The three elements usually considered of greatest concern to cetaceans are mercury, cadmium, and lead (O'Shea 1999). Mercury, cadmium, and other metals accumulate primarily in the liver and kidneys, whereas lead is deposited mostly in bones (Reijnders and Aguilar 2002). Concentrations of most metals tend to increase throughout an animal's life. Because metals are not lipophilic, females cannot significantly reduce their loads via reproductive transfer. Many marine mammal species are able to tolerate high amounts of metals or detoxify them (Reijnders and Aguilar 2002) and published accounts of metal-caused pathology are scarce (O'Shea 1999). To date, there has been little investigation of metals in killer whales in Washington and British Columbia. Small numbers of animals have been tested, with one stranded 17-year old male resident (L14) having high liver concentrations of mercury (reported as >600 mg/kg, wet weight, of which 14% was in the toxic methylated form, J. Calambokidis, unpubl. data; also reported as 1,272 mg/kg, wet weight, Langelier et al. 1990). An adult female transient (CA189) that stranded at Dungeness Spit in January 2002 carried the following metal levels (wet weight) in its liver: mercury, 129 mg/kg; cadmium, <0.15 mg/kg; and lead, <0.15 mg/kg (G. M. Ylitalo, unpubl. data). Stranded resident whales appear to carry higher amounts of mercury than transients (Langelier et al. 1990, cited in Baird 2001). With the exception of mercury, most metals do not bioaccumulate and are therefore unlikely to directly threaten the health of killer whales (Grant and Ross 2002). However, their greatest impact may be on prey populations and habitat quality.

Contaminant levels in prey. Relatively few studies have measured organochlorine loads in known or potential prey species of killer whales in Washington, British Columbia, and adjacent areas. However, growing evidence suggests that Puget Sound is a major source of contamination in prey, especially chinook salmon, which are thought to be a major food species for southern resident killer whales. New research indicates that chinook salmon from the sound possess much higher mean ΣPCB levels than chinook from other locations sampled along the western coast of North America (Table 8; S. M. O'Neill, unpubl. data). This work also reveals that Puget Sound chinook with long residency times in the sound have much greater ΣPCB burdens than those inhabiting the open North Pacific Ocean for much of their lives. Furthermore, among the five salmon species occurring in Puget Sound, the highest ΣPCB loads were carried by chinook, with moderate levels found in coho and low levels present in chum, sockeye, and pink salmon (S. M.

O'Neill, unpubl. data). Other research reveals that adult coho salmon returning to spawn in central and southern Puget Sound have higher ΣPCB concentrations than those returning to northern Puget Sound (West et al. 2001a). In English sole, rockfish, and herring, ΣPCB levels are influenced by the contaminant levels of local sediments. Thus, sole and rockfish living near contaminated urban areas often have higher burdens than those from non-urban sites (O'Neill et al. 1995, West et al. 2001b) and herring from central and southern Puget Sound possess greater burdens than those from northern Puget Sound and the Strait of Georgia (O'Neill and West 2001). Recent analyses of PCB levels in harbor seals indicate that seals and their prey in Puget Sound are seven times more contaminated than those in the Strait of Georgia (Cullon et al. 2004). In some long- lived fish species, PCB concentrations accumulate with age so that older individuals carry significantly higher burdens than younger individuals (O'Neill et al. 1995, 1998). In rockfish, this type of accumulation occurs only in males (West et al. 2001b). Pinnipeds and porpoises carry far greater amounts of PCBs and DDTs than baleen whales and fish (Table 8) because of their higher positions in food chains (O'Shea and Aguilar 2001, Reijnders and Aguilar 2002). For ΣPBDE concentrations, chinook salmon from British Columbia and Oregon carry substantially higher levels than other wild salmon populations in the northeastern Pacific (Hites et al. 2004). Salmon from Washington were not sampled in this study.

Sources of contaminants. Marine ecosystems in the northeastern Pacific receive pollutants from a variety of local, regional, and international sources (Grant and Ross 2002, EVS Environmental Consultants 2003, Garrett 2004), but the relative contribution of these sources in the contamination of killer whales is poorly known. Because resident killer whales carry increasingly higher chemical loads from Alaska to Washington (Ross et al. 2000a, Ylitalo et al. 2001), pollutants originating within Puget Sound and the Georgia Basin probably play a greater role in contamination than those from other sources. This pattern is apparent in chinook salmon with longer residency periods in Puget Sound, which carry considerably higher burdens of PCBs than populations from other areas (S. M. O'Neill, unpubl. data). Ross et al. (2000a) have suggested that elevated organochlorine concentrations in southern residents might result from their consumption of small amounts of highly contaminated prey near industrialized areas. Additionally, because most of the region's salmon populations are pelagic for long lengths of time, atmospheric deposition of PCBs and other pollutants in the North Pacific may be an important route for food chain contamination (Ross et al. 2000a). Sources of pollutants in transient whales are also difficult to decipher. Transients are highly contaminated throughout much of their distribution, but this very likely results from the higher trophic level and biomagnification abilities of their prey, as well as possibly from the widespread movements of many of these whales.

PCBs, polycyclic aromatic hydrocarbons (PAHs), and a number of other pollutants appear to occur at substantially higher levels in Puget Sound than elsewhere in Washington and southern British Columbia, including the Strait of Georgia, based on studies of contaminant loads in harbor seals, herring, and mussels (Hong et al. 1996, Mearns 2001, O'Neill and West 2001, Grant and Ross 2002, Ross et al. 2004, Cullon et al. 2004). This geographic pattern undoubtedly stems from greater contaminant inputs into Puget Sound due to human activities as well as the sound's lower rates of flushing and sedimentation (O'Neill et al. 1998, West et al. 2001a).

Table 8. Summary of ΣPCB and ΣDDT concentrations (mean ± SE, mg/kg, wet weight) in tissue samples from various mammal and fish species that are known or potential prey of resident and transient killer whales in Washington and neighboring areas. Results are combined for both sexes. A more complete listing of contaminant levels in marine mammals appears in Wiles (2004).

Species	Location	Age[a]	Tissue analyzed	Sample size	ΣPCBs	ΣDDTs	Reference
Chinook salmon	Puget Sound, s. Georgia Str, Wash.	4	muscle	66	.050 ± .005	.022 ± .001	O'Neill et al. (1995)
Chinook salmon	s. and c. Puget Sound, Wash.	-	muscle	34	.074	-	O'Neill et al. (1998)
Chinook salmon	Puget Sound, Wash.	A	muscle	211	.053	-	S. M. O'Neill (unpubl. data)
Chinook salmon	British Columbia	A	muscle	-	~ .018	-	S. M. O'Neill (unpubl. data)
Chinook salmon	Skeena River, B.C.	A	muscle	-	~ .006	-	S. M. O'Neill (unpubl. data)
Chinook salmon	Washington coast	A	muscle	-	~ .016	-	S. M. O'Neill (unpubl. data)
Chinook salmon	Columbia River	A	muscle	-	~ .017	-	S. M. O'Neill (unpubl. data)
Chinook salmon	Oregon	A	muscle	-	~ .010	-	S. M. O'Neill (unpubl. data)
Chinook salmon	Sacramento & San Joaquin Rivers, Calif.	A	muscle	-	~ .013	-	S. M. O'Neill (unpubl. data)
Coho salmon	Puget Sound, Wash.	A	muscle	221	.031	-	S. M. O'Neill (unpubl. data)
Coho salmon	s. and c. Puget Sound, Wash.	-	muscle	32	.035	-	O'Neill et al. (1998)
Coho salmon	Puget Sound, Wash.	3	muscle	47	.019 ± .002	.011 ± <.001	West et al. (2001a)
Pacific herring	Puget Sound, s. Georgia Str, Wash.	3	whole body	50	.102 ± .012	.029 ± .004	West et al. (2001a)
English sole	c. Puget Sound, Wash.[b]	-	muscle	18	.071	-	Landolt et al. (1987)
English sole	Puget Sound, s. Georgia Str, Wash.	6	muscle	113	.022 ± .002	.001 ± <.001	West et al. (2001a)
Quillback rockfish	Puget Sound, San Juan Isl., Wash.	14	muscle	83	.028 ± .003	.001 ± <.001	West et al. (2001a)
Brown rockfish	Puget Sound, San Juan Isl., Wash.	22	muscle	35	.027 ± .004	.002 ± <.001	West et al. (2001a)
Harbor seal	s. Puget Sound, Wash.	P	blubber	7	17.1 ± 2.1	2.2 ± 0.3[c]	Calambokidis et al. (1991)
Harbor seal	e. Strait of Juan de Fuca, Wash.	P	blubber	7	4.0 ± 2.5	1.5 ± 0.8[c]	Calambokidis et al. (1991)
Harbor seal	s. Puget Sound, Wash.	P	blubber	57	13.4 ± 1.1	2.0 ± 0.2	Calambokidis et al. (1999)
Harbor seal	s. Puget Sound, Wash.	P	blubber	17	18.1 ± 3.1	-	Ross et al. (2004)
Harbor seal	Georgia Strait, British Columbia	P	blubber	38	2.5 ± 0.2	-	Ross et al. (2004)
Harbor seal	Queen Charlotte Strait, B.C.	P	blubber	5	1.1± 0.3	-	Ross et al. (2004)
Harbor porpoise	Washington[d]	I,A	blubber	8	17.3 ± 3.9	14.4 ± 3.2[c]	Calambokidis and Barlow (1991)
Harbor porpoise	British Columbia[e]	C,I,A	blubber	7	8.4[f]	8.2[f]	Jarman et al. (1996)
Harbor porpoise	Oregon	C,I,A	blubber	13	10.9 ± 3.7	19.2 ± 4.5[c]	Calambokidis and Barlow (1991)
Harbor porpoise	central California	C,I,A	blubber	22	12.3 ± 2.0	41.5 ± 7.2[c]	Calambokidis and Barlow (1991)
Minke whale	s. Puget Sound, Wash.	-	blubber	1	.150	.550[b]	Calambokidis et al. (1984)
Gray whale	Washington	-	blubber	38	.220 ± .042	.130 ± .026	Krahn et al. (2001)

[a] Expressed as years of age or age category (A, adults; P, pups; C, calves; and I, immatures).
[b] Collected from Edmonds, Elliott Bay, Commencement Bay, and Bremerton.
[c] Only *p,p'*-DDE was measured.
[d] Collected primarily from the outer coast.
[e] Collected primarily from southern Vancouver Island.
[f] Results expressed as a geometric mean.

Recent analyses indicate that 1% of the marine sediments in Puget Sound are highly degraded by chemical contamination, whereas 57% show intermediate degrees of deterioration and 42% remain relatively clean (Long et al. 2001). Hotspots for contaminated sediments are centered near major urban areas, where industrial and domestic activities are concentrated. Locations of particular concern include Bellingham Bay, Fidalgo Bay, Everett Harbor and Port Gardner, Elliott Bay, Commencement Bay, Sinclair Inlet and other sites near Bremerton, and Budd Inlet (Long et al. 2001, EVS Environmental Consultants 2003), but contamination can extend widely into even some rural bays. Analyses of contaminants in fish and mussels suggest that some pollutants are most abundant in central and southern Puget Sound (Mearns 2001, O'Neill and West 2001, West et al. 2001a, EVS Environmental Consultants 2003). However, sediment testing indicates that the extent of contamination is broadly similar throughout the sound (Long et al. 2001). Summaries of contaminant presence in the Canadian waters of the Georgia Basin appear in Garrett (2004).

Marine pollutants originate from a multitude of urban and non-urban activities, such as improper disposal of manufacturing by-products, processing and burning of fossil fuels, discharge of leachate from landfills and effluent from wastewater treatment plants (Appendix B), agricultural use of pesticides, and terrestrial runoff. During the past few decades, regulatory actions, improved waste handling, and on-going cleanup efforts have led to marked improvements in regional water quality. Important actions taken include the cessation of PCB production and DDT use in the 1970s and the elimination of most dioxin and furan emissions from pulp and paper mills during the 1980s and early 1990s. Significant progress has been made in the cleaning and containment of the 31 Superfund sites in the Puget Sound basin, of which at least 11 leaked contaminants into coastal waters (Appendix C). Advances in the control of point-source pollution have also taken place. Environmental levels of many organochlorine residues (e.g., PCBs, dioxins, furans, organochlorine pesticides, and chlorophenols) have declined significantly during this period (Gray and Tuominen 2001, Mearns 2001, Grant and Ross 2002, EVS Environmental Consultants 2003). For example, mean ΣPCB concentrations in harbor seal pups from Puget Sound fell from more than 100 mg/kg, wet weight in 1972 to about 20 mg/kg, wet weight in 1990 (Calambokidis et al. 1999). Despite these improvements, the presence of some chemicals (e.g., PCBs and DDE) in coastal habitats and wildlife has stabilized since the early 1990s and is not expected to decline further for decades to come (Calambokidis et al. 1999, Grant and Ross 2002). By contrast, environmental levels of many emerging contaminants, which are typically poorly regulated, are probably increasing.

Atmospheric transport of pollutants is another important contaminant source for marine ecosystems. Due to the prevailing wind patterns of the Northern Hemisphere, a number of substances (e.g., PCBs, DDT, other pesticides, dioxins, furans, and metals) are carried in this manner from Asia to the northeastern Pacific (Iwata et al. 1993, Tanabe et al. 1994, Blais et al. 1998, Ewald et al. 1998, Jaffe et al. 1999, Ross et al. 2000a, Grant and Ross 2002, Lichota et al. 2004). Such contamination particularly affects the open North Pacific Ocean, where migratory salmon populations spend much of their lives maturing, but also impacts the coastal waters and land areas of Washington and British Columbia. Locally produced airborne pollutants (e.g., certain PCBs, dioxins, and furans) also enter coastal marine waters (Lichota et al. 2004).

Increased human population growth, urbanization, and intensified land use are projected for western Washington and southern British Columbia during the coming decades (Transboundary Georgia Basin-Puget Sound Environmental Indicators Working Group 2002) and will undoubtedly subject coastal ecosystems to greater contaminant input (Gray and Tuominen 2001, Grant and Ross 2002). Emissions from Asian sources are also expected to gradually expand and continue to reach the open North Pacific and mainland of northwestern North America. In particular, PCBs will likely remain a health risk for at least several more decades due to their persistence, their continued cycling in the environment through food webs and atmospheric processes, and the relative inability of marine mammals to metabolize them (Ross et al. 2000a, Calambokidis et al. 2001). Thus, exposure of the region's killer whales to contaminants is not expected to change appreciably in the foreseeable future (Grant and Ross 2002, Krahn et al. 2002).

Vessel Effects

Many marine mammal populations may be experiencing increased exposure to vessels and associated sounds. Commercial shipping, whale watching and recreational boating traffic has expanded in many regions in recent decades. In Washington, all three types of vessel traffic have grown over time. Underwater sound can be generated by engines, dredging, drilling, construction, seismic testing, and sonar (Richardson et al. 1995, Gordon and Moscrop 1996, National Research Council 2003). However, other than direct vessel strikes, potential impacts from these sources are poorly understood. Vessels have the potential to affect whales through the physical presence and activity of the vessel, the increased underwater sound levels generated by boat engines or a combination of these factors.

Killer whales rely on their highly developed acoustic sensory system for navigating, locating prey, and communicating with other individuals. Increased levels of anthropogenic sound have the potential to mask echolocation and other signals used by the species, as well as to temporarily or permanently damage hearing sensitivity. Exposure to sound may therefore be detrimental to survival by impairing foraging and other behavior, resulting in a negative energy balance (Bain and Dahlheim 1994, Gordon and Moscrop 1996, Erbe 2002, Williams et al. 2002a, 2002b). Furthermore, chronic stress from noise exposure, as well as repeated disturbance from vessel traffic, can induce harmful physiological conditions, such as hormonal changes, lowered immune function, and pathology of the digestive and reproductive organs in some species of marine mammals (Gordon and Moscrop 1996). The threshold levels at which underwater sounds becomes harmful to killer whales remain poorly understood (Krahn et al. 2002).

Whale watching. Whale watching has become an important tourist industry in many localities around the world since the early 1980s (Hoyt 2001, 2002). In addition to boosting the economies of coastal communities and providing an economic reason for preserving whale populations, whale watching has also proven beneficial by increasing public awareness of marine mammals and the environmental issues confronting them (Barstow 1986, Tilt 1986, Duffus and Deardon 1993, Lien 2001). In Washington and British Columbia, killer whales are the main target species of the commercial whale-watching industry, easily surpassing other species such as gray whales, porpoises, and pinnipeds (Hoyt 2001). Killer whale watching in the region is centered primarily on the southern and northern residents, which can be found more reliably than transients or offshores. Viewing activity occurs predominantly in and around Haro and Johnstone Straits, which are the summer core areas of the two resident communities. However, Haro Strait supports a considerably greater industry because of its proximity to urban areas. Both commercial and private vessels engage in whale watching, as well as kayaks and small numbers of aircraft. In addition, land-based viewing is popular at locations such as Lime Kiln Point State Park, San Juan County Park, and the San Juan County land bank on San Juan Island, Turn Point on Stuart Island, and East Point on Saturna Island (K. Koski, pers. comm.). Lime Kiln Point State Park was established in 1984 by the Washington State Parks and Recreation Commission for the purpose of watching killer whales (Ford et al. 2000) and receives about 200,000 visitors per year, most of whom hope to see whales (W. Hoppe, pers. comm.).

Commercial viewing of killer whales began in Washington and southern British Columbia in 1977 and persisted at a small scale through the early 1980s, with just a few boats operating and fewer than 1,000 passengers serviced per year (Osborne 1991, Baird 2002, Koski 2004). The first full-time commercial whale-watching vessel began frequent service in 1987 (Baird 2002). Activity expanded to about 13 active vessels (defined as making more than one trip per week) and 15,000 customers by 1988 (Osborne 1991), then jumped sharply from 1989 to 1998, when vessel numbers grew to about 80 boats and passenger loads increased to about half a million customers per year (Osborne et al. 2002). Small reductions in the numbers of companies, active boats, and passengers have occurred since then. About 37 companies with 73 boats were active in 2003; passenger levels were estimated at 450,000 people in both 2001 and 2002 (K. Koski, unpubl. data). Most companies belong to an industry organization known as the Whale Watch Operators Association Northwest, which was formed in 1994 to establish a set of whale viewing guidelines for commercial operators and to improve communication among companies (Whale Watch Operators Association Northwest 2003). The majority of commercial vessels were based in Washington during the 1980s, but this has gradually shifted so that Canadian boats comprised 68% of the industry in 2003 (Koski 2004). Most companies are based in Victoria or the San Juan Islands, but others operate from Bellingham, La Conner, Everett, Port Townsend, and Vancouver. Commercial whale-watching boats range in size and configuration from open vessels measuring under 7 m in length and capable of holding 6-16 people to large 30-m-long passenger craft that can carry up to 280 customers. Many boats routinely make two or three trips per day to view whales. Commercial kayaking operations include about six active companies that are focused on whale watching, plus another 18 companies or so that occasionally view whales (K. Koski, pers. comm.). At least one business offers occasional airplane viewing. The San Juan Islands and adjacent waters also attract large numbers of private boaters for recreational cruising and fishing. Many of these participate in viewing whales whenever the opportunity arises. Currently, about 65% of the craft seen with whales are commercially operated, with the remainder privately owned (Marine Mammal Monitoring Project 2002, Koski 2004). Additionally, private floatplanes, helicopters, and small aircraft take regular advantage of opportunities to view whales (Marine Mammal Monitoring Project 2002).

Hoyt (2001) assessed the value of the overall whale-watching industry in Washington at US$13.6 million (commercial boat-based viewing, $9.6 million; land-based viewing, $4.0

million) and in British Columbia at US$69.1 million (commercial boat-based viewing, $68.4 million; land-based viewing, $0.7 million) in 1998, based on estimated customer expenditures for tours, food, travel, accommodations, and other expenses. An estimated 60-80% of this value likely originated from the viewing of killer whales in the Georgia Basin and Puget Sound (R. W. Osborne, pers. comm.). More recent estimates of the economic value of whale watching in the region are unavailable. Expenditures by the users of private whale-watching vessels are also unknown.

The growth of whale watching during the past few decades has meant that killer whales in the region are experiencing increased exposure to vessels. Not only do greater numbers of boats accompany the whales for longer periods of the day, but there has also been a gradual lengthening of the viewing season. Commercial viewing activity during the summer now routinely extends from 9:00 a.m. to 9:00 p.m., with the heaviest pressure between 10:00 a.m. and 5:00 p.m. (Koski 2004; K. Koski, pers. comm.). However, some viewing may begin as early as 6:00 a.m. (Bain 2002). Thus, many resident whales are commonly accompanied by boats throughout much or all of the day. The commercial whale-watching season now usually begins in April, is heaviest during the warmer summer months, and largely winds down in October, but a small amount of traffic occurs throughout the winter and early spring whenever whales are present (K. Koski, pers. comm.). Viewing by private craft follows a similar seasonal pattern. J pod is considered the most commonly viewed pod, with L pod being the least viewed (Bain 2002; K. Koski, pers. comm.; R. W. Osborne, pers. comm.).

The mean number of vessels following groups of killer whales at any one time during the peak summer months increased from five boats in 1990 to 18-26 boats from 1996-2003 (Osborne et al. 1999, Baird 2001, Erbe 2002, Marine Mammal Monitoring Project 2002, Koski 2004). However, the whales sometimes attract much larger numbers of vessels. Annual maximum counts of 72-120 boats were made near whales from 1998-2003 (Koski 2004). In these cases, commercial vessels totaled no more than 35 craft, thus the majority of boats present were privately owned. Baird (2002) described one instance of a small fleet of 76 boats that simultaneously viewed about 18 members of K pod as they rested along the west side of San Juan Island in 1997. The ring of boats surrounding the whales included kayaks, sailboats, and a wide assortment of different-sized powerboats measuring up to about 30 m. Unusual occurrences of whales have the potential to draw even greater numbers of vessels. The month-long presence of killer whales at Dyes Inlet in Bremerton in the autumn of 1997 attracted up to 500 private whale-watching boats on weekends.

Worries that whale watching may be disruptive to killer whales date back to the 1970s and early 1980s, when viewing by relatively small numbers of vessels became routine (Kruse 1991). The expansion of commercial and private viewing in recent years has greatly added to concerns (Osborne 1991, Duffus and Deardon 1993, Lien 2001, Erbe 2002, Williams et al. 2002a, 2002b). The southern residents in particular have been exposed to noise generated by whale-watching vessels since the early 1990s (Bain 2002). This has caused whale-watching activity to be cited as possibly an important contributing factor in the recent decline of this population (Baird 2001, Bain 2002, Krahn et al. 2002, Wiles 2004). Whale-watching vessels can produce high levels of underwater sound in close proximity to the animals. Noise levels vary with vessel and engine type and become “louder” as speed increases (Bain 2002, Erbe 2002). Outboard-powered vessels operating at full speed produce estimated noise levels of about 160-175 decibels with reference to one microPascal at one meter (dB re 1 µPa hereafter) (Bain 2002, Erbe 2002). Inflatables with outboard engines are slightly “louder” than rigid-hull powerboats with inboard or stern-drive engines (Erbe 2002). Bain (2002) reported that the shift in predominance from American to Canadian-owned commercial craft during the 1990s has likely led to greater noise exposure for the whales. Many Canadian boats are small outboard powered craft, whereas most American vessels are larger and diesel powered. By modeling vessel noise levels, Erbe (2002) predicted that the sounds of fast boats are audible to killer whales at distances of up to 16 km, mask their calls up to 14 km away, elicit behavioral responses within 200 m, and cause temporary hearing impairment after 30-50 minutes of exposure within 450 m. For boats moving at slow speeds, the estimated ranges fall to 1 km for audibility and masking, 50 m for behavioral reactions, and 20 m for temporary hearing loss. It should be noted that underwater sound propagation can vary considerably depending on water depth and bottom type, thus noise measurements may not be applicable between locations (Richardson et al. 1995).

Several studies have linked vessels with short-term behavioral changes in northern and southern resident killer whales (Kruse 1991; Jelinski et al. 2002; Williams et al. 2002a, 2002b, Foote et al. 2004; J. Smith, unpubl. data) although whether it is the presence and activity of the vessel, the sounds of the vessel or a combination these factors is not well understood. Individuals can react in a variety of ways to whale-watching vessels. Responses include swimming faster, adopting less predictable travel paths, making shorter or longer dives, moving into open water, and altering normal patterns of behavior at the surface (Kruse 1991, Jelinski et al. 2002, Williams et al. 2002a; J. Smith, unpubl. data), while in some cases, no disturbance seems to occur (R. Williams, unpubl. data). Avoidance tactics often vary between encounters and the sexes, with the number of vessels present and their proximity, activity, size, and “loudness” affecting the reaction of the whales (Williams et al. 2002a, 2002b). Avoidance patterns often become more pronounced as boats approach closer. Kruse (1991) observed that northern resident whales sometimes reacted even to the approach of a single boat to within 400 m. This study also reported a lack of habituation to boat traffic over the course of one summer. However, further research by Williams et al. (2001, 2002a, 2002b) indicated a reduction in the intensity of northern resident responses to vessels between the mid-1980s and mid-1990s, possibly because of gradual habituation, changes in the avoidance responses of the whales, or sampling differences between the two studies. Foote et al. (2004) reported that call duration in the presence of whale-watching boats increased by 10-15% in each of the southern resident pods between 1989-1992 and 2001-2003, suggesting that animals were compensating for their noisier environment. Disturbance by whale-watching craft has also been noted to cause newborn calves to separate briefly from their mothers’ sides, which may lead to greater energy expenditures by the calves (J. P. Schroeder, pers. comm.).

Transient killer whales also receive considerable viewing pressure when they venture into the Georgia Basin and Puget Sound (Baird 2001). No studies have focused on their behavioral responses to whale-watching vessels to determine whether they resemble those of residents. Because transients may depend heavily on passive listening for prey detection (Barrett-Lennard et al. 1996), their foraging success is more likely affected by vessel presence than with residents (Ford and Ellis 1999, Baird 2001).

Whale-watching vessels generally employ one of two methods for approaching and viewing killer whales. “Paralleling” involves a boat that slowly cruises alongside the whales, preferably at a distance of greater than 100 m, as specified under current guidelines (see below). This style usually allows the passengers to see more of the whales and their behavior, but keeps them farther from the animals. The second technique is known as “leapfrogging” and involves a vessel that moves ahead of the whales by paralleling them for some distance at a faster speed (Williams et al. 2002b). The vessel then turns 90º to place itself directly in the whales’ anticipated path and waits for their approach while sitting in a stationary position with its engines put in idle or turned off. If the whales maintain their approximate travel course, they often swim closely past the boat or even underneath it, giving passengers a better close-up viewing opportunity. Private boaters usually engage in leapfrogging more than commercial operators (William et al. 2002b). Both styles of watching induce similar evasive responses by the whales, but leapfrogging appears to cause greater path deviation (Williams et al. 2002a, 2002b). Vessels speeding up to leapfrog also emit greater noise levels that are of higher frequency, and therefore have greater potential to mask communication in the whales than paralleling craft (Bain 2002). Furthermore, masking is more likely to occur from vessels placed in front of the whales (Bain and Dahlheim 1994, Bain 2002).

Researchers and photographers during the 1970s suspected that their own vessels affected killer whale behavior and developed an unofficial code of conduct intended to reduce the impacts of their activity on the whales (Bain 2002). These initial rules addressed the proximity between vessels and whales, vessel speeds, and the orientation of vessels relative to whales. As whale watching in Washington and southern British Columbia became increasingly popular, a set of voluntary guidelines was eventually established in the late 1980s by The Whale Museum in Friday Harbor to instruct commercial operators and recreational boaters on appropriate viewing practices. These also functioned as a proactive alternative to stricter legal enforcement of American and Canadian regulations (i.e., the Marine Mammal Protection Act and Fisheries Act, respectively), which prohibit harassment of the whales. In 1994, the newly formed Whale Watch Operators Association Northwest prepared an improved set of guidelines aimed primarily at commercial operators (Whale Watch Operators Association Northwest 2003). Regular review and updating of the guidelines has occurred since then. The current “Be Whale Wise” guidelines (Appendix A) were issued in 2002 with input from the operator’s association, whale advocacy groups, and governmental agencies. These guidelines suggest that boaters parallel whales no closer than about 100 m, approach the animals slowly from the side rather than from the front or rear, and avoid putting their vessel within about 400 m in front of or behind the whales. Vessels are also recommended to reduce their speed to about 13 km/hr within about 400 m of the whales and to remain on the outer side of whales near shore. A variety of other recommendations are also provided. Commercial operators have also agreed not to accompany whales into two areas off San Juan Island, an action that many private boaters follow as well. The first is a ½-mile (800 m)-wide zone along a 3-km stretch of shore centered on the Lime Kiln lighthouse. The area was designated in 1996 to facilitate shore-based viewing of whales and to reduce vessel presence in an area used preferentially by the whales for feeding, traveling, and resting. The second is a

¼-mile (400 m)-wide zone along much of the west coast of San Juan Island from Eagle Point to Mitchell Point. This was established in 1999 for the purpose of giving whales uninterrupted access to inshore habitats.

Most commercial whale-watching boats generally appear to honor the guidelines, with overall adherence rates improving over time (K. Koski, pers. comm.). However, infractions persist (Table 5). A greater problem lies with recreational boaters, who are much less likely to know about the guidelines and proper viewing etiquette (Lien 2001, Erbe 2002). As a result, several programs have been established to improve the awareness and compliance of private whale watchers, but these have had a beneficial impact on commercial operators as well. They include the Soundwatch Boater Education Program, which The Whale Museum has operated since 1993 largely through private grants and donations. A Canadian counterpart program known as the Marine Mammal Monitoring Project (M3) began in 2001 through the Veins of Life Watershed Society, with principal funding from the Canadian federal government. Both programs work cooperatively in the waters of both countries. A third program known as Straitwatch has operated in the vicinity of Johnstone Strait under the guidance of the Johnstone Strait Killer Whale Interpretive Centre Society since 2002. The programs educate the boating public through several methods, the most visible of which is the use of small patrol boats that are on the water with whale-watching vessels on a daily basis during the peak whale-watching season. Crews do not have enforcement capability, but monitor and gather data on boater activities and inform boat operators of whale-watching guidelines and infractions. Monitoring of commercial craft is also performed. Program staff also distribute informational materials and give public presentations to user groups. These programs have been very successful in improving the overall behavior of recreational and commercial whale watchers, especially when their patrol craft are operating on the scene (J. Smith, unpubl. data; K. Koski, pers. comm.).

Table 5. Types and relative occurrence of infractions of voluntary whale-watching guidelines witnessed by the Soundwatch Boater Education Program in Washington and southern British Columbia, 1998-2002 (data provided by The Whale Museum's Soundwatch Boater Education Program). Infractions were committed by commercial and recreational vessels and aircraft in the act of whale watching.

Type of infraction	Percent of infractions[a]
Parked in path of whales[b]	31.6
Within the 400-m-wide San Juan Island no-boat zone	21.4
Inshore of whales	20.8
Other[c]	7.6
Aircraft within 300 m of whales	6.4
Under power within 100 m of whales	5.0
Crossing the path of whales	3.6
Chasing or pursuing whales	2.0
Within the 800-m-wide Lime Kiln no-boat zone	1.8
Total	100.2

[a] Based on 2,634 infractions observed from 1998-2002.
[b] Includes leapfrogging and repositioning.
[c] Includes a variety of infractions, such as repeated circling by aircraft, operating a vessel at fast speeds within 400 m of whales, drifting into the path of whales, and operating a vessel within the protected zone around seabird nesting areas and marine mammals haul-out sites.

Aircraft are not specifically mentioned in the “Be Whale Wise” guidelines. However, recommendations for aircraft are incorporated into a broader set of regional whale-watching guidelines prepared by the National Marine Fisheries Service. These advise aircraft to maintain a minimum altitude of 300 m (1,000 ft) above all marine mammals, including killer whales, and to not circle or hover over the animals. Violations of these recommendations have dramatically risen in the past four years and now represent about 10% of all infractions observed (Marine Mammal Monitoring Project 2002; K. Koski, unpubl. data).

The potential impacts of whale watching on killer whales remain controversial and inadequately understood. Although numerous short-term behavioral responses to whale-watching vessels have been documented, no studies have yet demonstrated a long-term adverse effect from whale watching on the health of any killer whale population in the northeastern Pacific. Both resident populations have shown strong site fidelity to their traditional summer ranges despite more than 25 years of whale-watching activity. Furthermore, northern resident abundance increased throughout much of this period, suggesting that this population was not affected to any great extent until perhaps recently. The current decline of the southern resident population does not appear to follow a simple cause-and-effect relationship with the expansion of whale watching. Indeed, the statistical analyses of Bain (2002) most strongly indicated that the whale-watching fleet’s buildup tracked the decline of the population from 1991-2001. Bain (2002) therefore speculated that a complex relationship with additional variables might be at work. Further confounding the matter is the fact that the heaviest watched pod (J pod) has shown an overall increasing trend in numbers since the 1970s and is currently at its highest recorded number. In contrast, L pod is considered the least viewed pod, but is the only one to undergo a substantial and continuing decline since 1996. It is important to note that research findings on the responses of the northern residents to vessel traffic are not necessarily applicable to the southern residents, which are exposed to much heavier viewing pressure (Williams et al. 2002a). Some researchers believe that the southern residents are more habituated to vessel traffic and have perhaps adapted to some of its adverse impacts. Nevertheless, concerns remain that populations may be experiencing subtle cumulative detrimental effects resulting from frequent short-term disturbance caused by whale watching. If recent levels of whale watching are indeed problematic for the southern residents, the population has much less opportunity than the region’s other killer whale communities to relocate to other productive feeding areas with less disturbance (Bain 2002).

Other vessels. Commercial shipping traffic is believed to be a major source of low frequency (5 to 500 Hz) human-generated sound in the world’s oceans (National Research Council 2003). The Georgia Basin and Puget Sound are among the busiest waterways in the world, with several thousand trips made per month by various types of commercial vessels. Haro Strait, which is frequently used by southern resident killer whales, is one of the region’s primary shipping lanes. Non-recreational vessel traffic in Puget Sound, the eastern Strait of Juan de Fuca, and the southern Strait of Georgia is dominated by cargo ships (34% of all traffic, as measured in total ship hours), passenger vessels (31%), tugs (17%), and tankers (9%) (Mintz and Filadelpho 2004a). The low-frequency noise radiated by these ships comes largely from cargo ships (71%), passenger vessels (13%), tugs (7%), and tankers (5%) (Mintz and Filadelpho 2004b). By comparison, traffic inside the western half of the Strait of Juan de Fuca and off the Washington coast is comprised mainly of cargo ships (51%), tugs (15%), tankers (14%), and fishing vessels (9%), with most noise coming from cargo ships (86%), tankers (6%), and tugs (5%) (Mintz and Filadelpho 2004a, 2004b). In both areas, Navy vessels typically make up 2-3% of the traffic and ≤1% of the radiated engine noise, because of their noise-reducing designs, but this does not account for sound associated with high-power mid-frequency tactical sonar use. Koski (2004) reported that commercial shipping vessels made up 1-2% of the craft recorded near southern resident whales in and around the San Juan Islands during the summers of 2003 and 2004. The inland waters of Washington and southern British Columbia historically supported a major fishing industry centered on salmon, but changes in fishing regulations and declines in salmon abundance have reduced the number of commercial fishing boats present in recent decades. Recreational fishing boats remain common in the area and comprised 11% of the vessels observed in the vicinity of the southern residents from June-September 2003 (Koski 2004). When operating at slow speeds or in idle, these boats usually do not appear to disrupt the whales' behavior (Krahn et al. 2004a).

Under certain conditions, the high sound pressure levels generated by some sonar may impact marine mammals (U.S. Department of Commerce and Secretary of the Navy 2001). If sound levels received by marine mammals are high enough, temporary or permanent hearing loss may occur, and in severe cases, may result in hemorrhaging around the brain and ear bones. Killer whale hearing sensitivity ranges from 1 to 120 kHz with peak sensitivities from 20 to 50 kHZ (Szymanski et al. 1999) and fully covers the bandwidth generally considered as mid-frequency (2 to 10 kHz). Threshold levels at which underwater anthropogenic sounds negatively impacts hearing and behavior are poorly understood. In dolphins, the onset of hearing loss has been estimated to occur at received sound pressure levels of 195 dB at 1 sec duration exposures (Schlundt et al. 2000), while avoidance behaviors in a range of species exposed to different sound sources, other than mid-frequency sonar, have been observed at received levels of 140-160 dB (Malme et al. 1983, 1984, 1988, Ljungblad et al. 1988, Tyack and Clark 1998).

Military mid-frequency tactical sonar is another issue that has been associated with vessels operating in Puget Sound. Current tactical military sonar designs, such as the U.S. Navy's AN/SQS-53C tactical sonar produce signals with source levels of 235 rms dB re 1 µPa at 1 m. Strandings of cetaceans have been linked to naval sonar use (U.S. Department of Commerce and Secretary of the Navy 2001). In March 2000, a multi-species stranding of 17 cetaceans was discovered in the Bahamas and coincided with ongoing naval activity involving tactical mid-frequency sonar. Gross findings during exams of the animals that died included acute hemorrhage within the inner ear, subarachnoid space, and lateral ventricles (U.S. Department of Commerce and Secretary of the Navy 2001). A possible mechanism for sonar-related marine mammal strandings is the formation of nitrogen bubbles in diving mammals exposed to intense acoustic exposures (Jepson et al. 2003). However, the exposure conditions required to induce such gas emboli in marine mammals, including killer whales, are poorly understood.

The impacts of military sonar on killer whales have not been studied, but observations are available from an event that occurred in the Strait of Juan de Fuca and Haro Strait on 5 May

2003, when members of J pod were present off southwestern San Juan Island. A U.S. Navy guided-missile destroyer (*USS Shoup*) passed through the strait while operating its mid-frequency AN/SQS-53C sonar during a training exercise. Members of J pod were present in the strait and unusual behaviors by whales in response to the sound were reported by local researchers (NMFS 2004d, U.S. Navy, Pacific Fleet 2004). NOAA assessed the acoustic exposures and reported that it was unlikely that the whales experienced either temporary or permanent hearing loss. Based on the duration and received levels, and levels known to cause behavioral reactions in other cetaceans, J pod received exposure levels likely to cause behavioral disturbance, which is consistent with eyewitness accounts (NMFS 2004d).

Only a few Navy vessels operating in the greater Puget Sound area are equipped with mid-range frequency active sonar. Typical Navy mid-frequency active sonar use in Puget Sound is limited to pier-side system maintenance and training on designated ranges. As a precautionary measure, any ship, submarine or unit wanting to use active sonar in Puget Sound, including the Strait of Juan de Fuca, is required to obtain prior permission from Commander, U.S. Pacific Fleet.

Committed to protecting marine mammals in Puget Sound, the Navy has and will continue to work closely with NOAA Fisheries Service and has already proactively established procedures to minimize any potential harm to marine mammals from sonar use. The Navy avoids training in major marine mammal concentration areas when possible, listens for vocalizing animals with passive sonar prior to commencing exercises, and suspends or ceases sonar operations when marine mammals are detected to minimize any potential risk of harm. Navy protective measures also include posting highly trained lookouts that are especially adept at spotting and identifying small objects at sea under all conditions. Reports of marine mammal activity are passed on to command personnel to ensure Navy vessels avoid marine mammals. The Navy coordinates with NOAA Fisheries Service on necessary authorizations under the MMPA and ESA on many activities where impacts on protected resources may occur as contemplated by the legislation. Continued coordination with NOAA Fisheries Service as federal partners will insure that were any future potential impacts to be identified, that adequate conservation measures would be in place.

Canadian military authorities maintain a munitions testing area near Bentinct Island and Pedder Bay at the southern tip of Vancouver Island. Underwater detonations are sometimes performed at the site and occurred on one occasion when J pod was less than 1.5 km away, which caused the whales to suddenly change their direction of travel (R. W. Baird, pers. comm.). The U.S. Navy operates several ordnance training locations in Puget Sound. Ordnance training activities include procedures to ensure marine mammals are not in the vicinity and likely have little impact on the species.

Commercial sonar systems designed for fish finding, depth sounding, and sub-bottom profiling are widely used on civilian vessels and are often characterized by high operating frequencies, low power, narrow beam patterns, and short pulse lengths (National Research Council 2003). Frequencies fall between 1 and 500 kHz, thus some systems function within the hearing range of killer whales and may have masking effects. Little information is currently available on any potential impacts of multiple commercial sonars used in close proximinty of killer whales, but impact zones would likely be very small, based on the high frequencies and short durations of most depth sounders and fish finders.

Seismic surveying is the primary exploration technique for oil and gas deposits in offshore areas and for fault structures and other geological hazards offshore. Surveys are carried out by ships towing one or two arrays of air-guns, which generate intense low-frequency sound pressure waves capable of penetrating the seafloor and are fired repetitively at 10-20-second intervals for extended periods (National Research Council 2003). Arrays hold up to 70 air-guns and commonly vary from 2,000-8,000 cu in (0.033-0.131 m^3) in total size. Most of the energy from the guns is directed vertically downward, but significant sound emission also occurs horizontally. If downward directed pulses enter the deep sound channel (about 800 m depth or more) they may be detected at distances exceeding 3,000 km (Nieukirk et al. 2004). Peak pressure levels from air-guns usually range from 5-300 Hz and reach about 235-240 dB re 1 µPa (RMS, far field measurement) (National Research Council 2003) and most of the energy is below 500 Hz. When fish were exposed to air guns far more intensively than they would in a typical seismic survey damage to the ears of fish resulted (McCauley et al. 2003). In the United States, all seismic projects for oil and gas exploration and most research applications, with the potential to take marine mammals, are covered by incidental harassment authorizations under the MMPA.

Underwater acoustic deterrent devices. In addition to vessel related sounds, acoustic harassment devices are a source of sound. The use of acoustic harassment devices at salmon aquaculture farms represents another source of disruptive noise for killer whales in Washington and British Columbia. The devices emit “loud” signals that are intended to displace harbor seals and sea lions away from the farms, thereby deterring predation (Petras 2003), but can cause strong avoidance responses in cetaceans as well (Olesiuk et al. 2002). Morton and Symonds (2002) described one model that broadcast a 10 kHz signal at 194 dB re 1 µPa at 1 m and was potentially audible in open water for up to 50 km. During the early 1990s, the devices were installed at a number of salmon farms in Washington (including Cypress Island, Port Angeles, Rich Passage off Bainbridge Island, and Squaxin Island) and British Columbia, but were phased out of operation in Washington after just a few years (D. Swecker, pers. comm.; J. K. B. Ford, pers. comm.). Activation of the devices at a farm near northeastern Vancouver Island corresponded with drastic declines in the use of nearby passages and inlets by both resident and transient whales (Morton and Symonds 2002). It is unknown whether the devices ever produced similar impacts on killer whales in Washington or elsewhere in British Columbia. The only device still in use in Washington operates at the Ballard locks in Seattle, where the National Marine Fisheries Service utilizes it primarily during the spring steelhead run.

Oil Spills

Exposure to petroleum hydrocarbons released into the marine environment via oil spills and other discharge sources represents another potentially serious health threat for killer whales in the northeastern Pacific. Marine mammals are generally able to metabolize and excrete limited amounts of hydrocarbons, but acute or chronic exposure poses greater toxicological risks (Grant and Ross 2002). Unlike humans, cetaceans have a thickened epidermis that greatly reduces the likelihood of petroleum toxicity from skin contact with oiled waters (Geraci 1990, O’Shea and

Aguilar 2001). Inhalation of vapors at the water's surface and ingestion of hydrocarbons during feeding are more likely pathways of exposure. Transient killer whales may be especially vulnerable after consuming prey debilitated by oil (Matkin and Saulitis 1997). Matkin et al. (1994) reported that killer whales did not attempt to avoid oil-sheened waters following the *Exxon Valdez* oil spill in Alaska. In marine mammals, acute exposure to petroleum products can cause changes in behavior and reduced activity, inflammation of the mucous membranes, lung congestion, pneumonia, liver disorders, and neurological damage (Geraci and St. Aubin 1990). Evidence of direct mortality in killer whales from spills is described elsewhere in this report (see *Incidental Human-Related Mortality*). Oil spills are also potentially destructive to prey populations and therefore may adversely affect killer whales by reducing food availability.

Due to its proximity to Alaska's crude oil supply, Puget Sound is one of the leading petroleum refining centers in the U.S., with about 15 billion gallons of crude oil and refined petroleum products transported through it annually (Puget Sound Action Team 2005). Inbound oil tankers carry crude oil to four major refineries in the sound, while outbound tankers move refined oil products to destinations along the U.S. west coast (Neel et al. 1997). In 2003, a total of 746 oil tankers passed through Washington's waters bound for ports in Puget Sound, Canada, and along the Columbia River (Washington Department of Ecology 2004). This volume of shipping traffic puts the region at risk of having a catastrophic oil spill. The proposed removal of the current moratorium on oil and gas exploration and development off the British Columbia coast will increase the danger of a major accident in the region. The possibility of a large spill is considered one of the most important short-term threats to killer whales and other coastal organisms in the northeastern Pacific (Krahn et al. 2002).

Neel et al. (1997) reported that shipping accidents were responsible for the largest volume (59%; 3.4 million gallons [12.9 million liters]) of oil discharged during major spills in Washington from 1970-1996. Other sources were refineries and associated production facilities (27%; 1.5 million gallons [5.7 million liters]) and pipelines (14%; 800,000 gallons [3.0 million liters]). There have been eight major oil tanker spills exceeding 100,000 gallons (378,500 liters) in the state's coastal waters and on the Columbia River since the 1960s, with the largest estimated at 2.3 million gallons (8.7 million liters) (Table 9). Grant and Ross (2002) did not report any major vessel spills from British Columbia during this same period, but at least one of 100,000 gallons (379,000 liters) is known to have occurred in Canadian waters at the mouth of the Strait of Juan de Fuca in 1991 (Neel et al. 1997). In addition to these incidents, there have been a number of near accidents resulting from vessel groundings, collisions, power loss, or poor vessel condition (Neel et al. 1997).

Puget Sound's four oil refineries are coastally located at Anacortes (Shell Oil and Texaco), Ferndale (Mobil Oil), and Tacoma (US Oil). Four major spills have occurred at two of these facilities (Table 9), with each causing some discharge of petroleum into marine waters (D. Doty, pers. comm.). Pipelines connecting to refineries and oil terminals at ports represent another potential source of coastal spills. Pipeline leaks have caused several major spills in western Washington, but only the 1999 Olympic spill resulted in any discharge to marine waters (Neel et al. 1997; G. Lee, pers. comm.).

Table 9. Oil spills of 100,000 gallons or more from vessels, production facilities, and pipelines in Washington from the 1960s to 2003 (from Neel et al. 1997, Puget Sound Action Team 2002).

Year	Incident name	Location	Amount spilled (gallons)	Type of product
Vessels				
1972	*General M. C. Meiggs*	Cape Flattery	2,300,000	Heavy fuel oil
1964	United Transportation barge	n. Grays Harbor Co.	1,200,000	Diesel fuel
1985	*ARCO Anchorage*	Port Angeles	239,000	Crude oil
1988	*Nestucca* barge	Ocean Shores	231,000	Heavy fuel oil
1971	United Transportation barge	Skagit County	230,000	Diesel fuel
1984	*SS Mobil Oil* tanker	Columbia R., Clark Co.	200,000	Heavy fuel oil
1978	Columbia River barge	Klickitat County	100,000	Diesel fuel
1991	*Tenyo Maru*	Strait of Juan de Fuca[a]	100,000	Heavy fuel oil, diesel
Refineries				
1991	US Oil	Tacoma	600,000	Crude oil
1993	US Oil	Tacoma	264,000	Crude oil
1991	Texaco	Anacortes	210,000	Crude oil
1990	Texaco	Anacortes	130,000	Crude oil
Pipelines				
1973	Trans-Mountain	Whatcom County	460,000	Crude oil
1999	Olympic	Bellingham	277,000	Gasoline
1983	Olympic	Skagit County	168,000	Diesel fuel

[a] Spill occurred in Canadian waters at the mouth of the Strait of Juan de Fuca and flowed into Washington.

During the late 1980s and early 1990s, Washington significantly upgraded its efforts to prevent oil spills in response to increased numbers of spills in the state and the *Exxon Valdez* accident in Alaska. A number of state, provincial, and federal agencies now work to reduce the likelihood of spills, as does the regional Oil Spill Task Force, which was formed in 1989. National statutes enacted in the early 1990s, including the U.S.'s Oil Pollution Act in 1990 and the Canada Shipping Act in 1993, have also been beneficial in creating spill prevention and response standards. Since 1999, Washington State has maintained a rescue tugboat at Neah Bay for about 225 days per year during the winter months to aid disabled vessels and thereby prevent oil spills. These measures appear to have been helpful in reducing the number and size of spills since 1991, but continued vigilance is needed (Neel et al. 1997). In general, Washington's outer coast, the Strait of Juan de Fuca, and areas near the state's major refineries are considered the locations most at risk of major spills (Neel et al. 1997).

Chronic small-scale discharges of oil into oceans greatly exceed the volume released by major spills (Clark 1997) and represent another potential concern. Such discharges originate from numerous sources, such as the dumping of tank washings and ballast water by tankers, the release of bilge and fuel oil from general shipping, and the disposal of municipal and industrial wastes. Chronic oil pollution kills large numbers of seabirds (e.g., Wiese and Robertson 2004), but its impact on killer whales and other marine mammals is poorly documented. The long-term effects of repeated ingestion of sub-lethal quantities of petroleum hydrocarbons on marine mammals are also unknown.

Disease

Infectious diseases are not known to limit any killer whale population, nor have epidemics been recorded in the species. Nevertheless, a variety of pathogens have been identified in killer whales, while others occur in sympatric marine mammal species and may therefore be transmittable to killer whales (Gaydos et al. 2004). Several highly virulent diseases have emerged in recent years as threats to marine mammal populations. Of particular concern are several types of virus of the genus *Morbillivirus*. These include 1) dolphin morbillivirus, which killed several thousand striped dolphins (*Stenella coeruleoalba*) in the Mediterranean Sea during the early 1990s (Aguilar and Borrell 1994b) and unknown numbers of bottlenose dolphins in the western Atlantic during the late 1980s and Gulf of Mexico in the mid-1990s (Kennedy 1999, 2001), 2) phocine distemper virus, which produced large die-offs of harbor seals and gray seals in Europe in the late 1980s and 2002 (Hall et al. 1992, Jensen et al. 2002), and 3) canine distemper virus, which caused mass mortalities among Baikal seals (*Phoca sibirica*) in the late 1980s and Caspian seals (*P. caspica*) in 2000 (Kennedy et al. 2000, Kennedy 2001). PCB-caused suppression of the immune system is thought to have increased susceptibility to the virus in many of these cases (de Swart et al. 1996, Ross et al. 1996b, Ross 2002), although this conclusion is the subject of debate (O'Shea 2000a, 2000b, Ross et al. 2000b). Genetic inbreeding may have also played a role in the deaths of some infected striped dolphins (Valsecchi et al. 2004). Morbillivirus infections have been diagnosed in a variety of other marine mammals from the Atlantic, but caused little mortality in most instances (Kennedy 2001). Antibodies to dolphin morbillivirus have also been detected in common dolphins (*Delphinus delphis*) from southern California (Reidarson et al. 1998), placing the virus inside the ranges of transient and offshore killer whales and near the known southern limit of the southern resident community (Gaydos et al. 2004). Additionally, there have been recent detections of canine distemper virus in river otters in British Columbia (Mos et al. 2003) and evidence of exposure to a canine- or phocine-like morbillivirus in sea otters from the Olympic Peninsula (J. Davis, unpubl. data). Because of the mutation capabilities and species-jumping history of morbilliviruses, there is a possibility that these forms could infect killer whales even if they are not the dolphin type (J. Gaydos, pers. comm.). Limited testing evidence suggests that killer whales have not yet been affected by morbilliviruses in Washington, British Columbia, or elsewhere in the world (Van Bressem et al. 2001), although small sample sizes precludes a thorough assessment of this issue. The fact that southern resident killer whales are likely seronegative suggests that they may be vulnerable if exposed to such a virus (P. S. Ross, pers. comm.) Morbillivirus outbreaks are also of concern because of their potentially rapid rates of spread (i.e., up to 4,000 km per year) in marine environments (McCallum et al. 2003).

Other diseases such as *Brucella* spp. and cetacean poxvirus may impact killer whale populations by lowering reproductive success or causing greater mortality among calves (Gaydos et al. 2004). The southern resident community is perhaps the most vulnerable of the four populations in Washington and British Columbia to a serious disease outbreak due to its gregarious social nature, smaller population, seasonal concentration near the San Juan Islands, and high levels of PCB contamination (Gaydos et al. 2004).

Inbreeding and Other Small Population Effects

Small populations of animals can experience a host of problems that result in decreased per capita birth rates (i.e., inverse density dependence), a phenomenon known as the Allee effect. Under such conditions, factors such as loss of genetic variability, genetic drift, demographic fluctuations, and declining opportunities for cooperative behavioral interactions can work alone or additively to cause the eventual extinction of populations that have fallen below a critical density (Courchamp et al. 1999).

Small population sizes often increase the likelihood of inbreeding, which can lead to the accumulation of deleterious alleles, thus causing decreased reproductive rates, reduced adaptability to environmental hazards such as disease and pollution, and other problems (Barrett-Lennard and Ellis 2001, Valsecchi et al. 2004). Such effects are highly variable among species, with some strongly impacted and others much less so. A number of the killer whale communities in the northeastern Pacific contain fewer than 500 individuals, which is usually considered very small for discrete populations of most species (Barrett-Lennard and Ellis 2001, Frankham et al. 2002). Nevertheless, these communities appear adept at avoiding matings between members of the same pod. This may be an adaptation to small group size and suggests that the populations are genetically more viable when small than those of most species (Barrett-Lennard and Ellis 2001). Recent analyses indicate that the southern residents are no less genetically diverse than other resident populations (Hoelzel 2004). Thus, the southern residents are probably not at immediate risk from inbreeding depression. However, because of its recent decline, this community now contains just 28 reproductively active individuals. The deaths of several adult males in J and K pods between 1995 and 1998 have left the females of L pod with only one fully adult male (J1) to mate with during the past five years. This situation could lead to a loss of genetic variability in the population (Center for Biological Diversity 2001, Krahn et al. 2004a), possibly resulting in inbreeding depression in the future.

Allee effects may influence small populations of killer whales in a variety of other ways that ultimately lower overall reproductive performance or survivorship. Because the species hunts cooperatively, declining group sizes may result in decreased foraging efficiency and energy acquisition per individual (e.g., Baird and Dill 1996). This may be particularly true for resident whales searching for aggregations of dispersed prey such as salmon. Changes in sex ratio and declines in various age cohorts may take on greater importance in small populations. For example, declines in numbers of breeding males, such as seen in the southern residents since 1987, may increase the difficulty that sexually receptive females have in finding suitable mating partners. Resident killer whales display some of the most advanced social behavior of any non-human mammal, as evidenced by their highly stable social groupings, complex vocalization patterns, the presence of long-lived post-reproductive females, and behaviors such as cooperative foraging, food sharing, alloparental care, matriarchal leadership, and innovative learning. Maintenance of minimal group sizes is therefore probably necessary in preserving beneficial social interactions and in raising young.

Cumulative Effects of Multiple Chronic Stressors

It is not clear, and may be impossible to quantify or model, which of the chronic stressors the southern resident killer whale population is subject to is the most important. Disruption of foraging behavior, either from proximity of whale-watching boats or reduction of preferred prey species may introduce a stressor exacerbating the immunosuppressive effects of accumulated contaminants in the blubber and other tissues of each individual killer whale. Adequate nutrition is the basis for maintaining homeostasis, but if a killer whale is unable to eat for some period of time due to anthropogenic stressors, blubber stores become mobilized leading to higher blood levels and increased negative effects to health and/or fecundity.

There are cumulative effects of chronic stressors within risk factors as well. The well-documented effects of contamination by persistent organic pollutants on both immunologic dysfunction and reproductive abnormalities (Table 7) indicate they are linked. While it may not be possible to discern which effects have the most significant impact, it may be a combination of effects on both systems or there may be age and sex differences in whether immune or reproductive functions are most affected. Obviously, no breeding will occur if killer whales die of disease they acquire due to reduced immune capacity. PCBs and other oganochlorines affect both systems, but re-breeding and trying again may compensate for reduced survival of neonates. Not all bacterial diseases cause death. Morbillivirus causes greater mortality than brucellosis, but a chronic brucellosis infection may cause stillborn calves and may eventually lead to death of the host due to secondary complications, generally related to an exhausted immune system. Some breeding can occur in spite of compromised immune systems. Polar bear studies (Skaare et al. 2002) indicate that birth rates and testosterone levels are reduced in contaminated animals. The immune system may become dysfunctional even at very low concentrations of contaminants and before other systems are compromised (Skaare et al. 2002).

OPTIMUM SUSTAINABLE POPULATION CRITERIA

The MMPA states that the goal of a conservation plan is to conserve and restore the species or stock to its optimum sustainable population. Optimum sustainable population is defined as the number of animals which will result in the maximum productivity of the population or the species keeping in mind the carrying capacity of the habitat and the health of the ecosystem.

Developing conservation goals is challenging. While the southern residents have been studied for more than 30 years, there are still many unknowns. For example, little is known about historical population abundance and distribution, or whether the list of factors threatening the species is complete. The relative significance of threats to the species and how those threats interact or contribute to cumulative effects are also unknown. Similarly, information on how killer whales use their habitat and the importance of habitat features to the basic biology of the species or to carrying capacity are areas of considerable uncertainty.

We will consider all available information in developing criteria for conservation of southern resident killer whales, including input from the public, research community, co-managers, and other parties with pertinent information.

Southern and northern resident killer whales are listed as endangered and threatened, respectively, under the Species at Risk Act (SARA) in Canada. Pursuant to SARA a Killer Whale Recovery Team (KWRT) was formed to develop a recovery strategy for both populations in British Columbia. In their deliberations, the KWRT has developed a draft objective for ensuring the long-term viability of the populations and identifying the conditions required for recovery. The conditions do not speak directly to habitat or threat mitigation, but focus instead on population metrics and diversity. The conditions required for recovery, as discussed by the KWRT, are as follows:

- Maintenance of a non-negative long-term growth rate for populations currently at known historic maximum levels (northern residents) and a positive long-term growth rate for populations currently below known historic maximum levels;
- Maintenance of sufficient numbers of females in the population to ensure that their combined reproductive potential is at replacement levels for populations currently at known historic maximum levels and above replacement levels for populations currently below known historic maximum levels;
- Maintenance of sufficient numbers of males in the population to ensure that breeding females have access to multiple potential mates outside of their own and closely related matrilines; and
- Maintenance of matrilines comprised of multiple generations to ensure continuity in the transmission of cultural information affecting survival.

These conditions for recovery outlined in the discussions of the KWRT are consistent with the concepts of optimum sustainable population.

In developing optimum sustainable population criteria, there are a number of important questions to consider as we move forward.

- **What was the historical population abundance/carrying capacity**?
  To our knowledge, the abundance of southern resident killer whales has never been large (i.e., order(s) of magnitude larger than the current population size). Studies indicate that resident populations tend toward small reproductively isolated groups with overlapping but reasonably discrete core ranges. Estimates place the historical maximum in the range of 140 to 200 individuals (68 FR 31982, May 29, 2003), but the actual historical abundance is unknown. In the absence of early population counts the estimated historical maximum can be considered as a proxy for the population at carrying capacity.

- **Has carrying capacity of the environment changed in recent times?**
  There is significant uncertainty over the status of current carrying capacity of the environment for the southern resident population relative to historical carrying capacity.

- **Are the southern residents a closed population?**
  There is insufficient data from the southern resident population to determine if matings are occurring between southern females and males from other populations but the incidence is assumed to be small.

- **Is there adequate reproduction for replacement of losses due to natural mortality?**
  The southern residents represent an almost unprecedented situation where there is detailed individual-based data that allows for demographic assessment. For example, the age and sex structure can be measured to assess reproductive potential.

- **How much genetic diversity is needed to sustain the population?**
  Genetic diversity is known to be low in the southern resident population, but the significance of this lack of diversity has not been assessed. There appear to be only limited opportunities for genetic mixing to occur within the population. Females are not known to migrate between resident populations, but studies indicate that males nearly always mate outside of their pod (i.e., outside of the closely related matrilines).

- **How do individual males contribute to genetic diversity?**
  The significance of social dominance between males of mating age from different pods is poorly understood.

- **What is the relative importance of different threats and what are the cumulative effects?**

CONSERVATION PROGRAM

Below is an outline of actions necessary to alleviate threats and restore the southern resident killer whale population to long-term sustainability. The outline includes management actions, monitoring necessary to track the effectiveness of these actions and the status of the population, and research activities to fill critical data gaps. Ongoing programs in place to address killer whale conservation are also given. The outline is intended to provide guidance to resource managers, stakeholders, industry, and the public. Parties with authority, responsibility, or expressed interest to implement a specific conservation action are identified in the Implementation Schedule. Note that the ranking of activities listed below does not imply an order of importance. The priority of each action, plus a cost and timeline for completion, appear in the Implementation Schedule.

Conservation Action Narrative

1. Monitor status and trends of the southern resident killer whale population.

1.1 Continue the annual population census.

Annual photo-identification surveys remain one of the most important activities involving southern resident killer whales. Counts are performed by the Center for Whale Research and provide a complete yearly inventory of the population dating back to 1974. Counts are conducted by boat primarily in and around the San Juan Islands during June and July, with supplementary information gathered whenever the whales can be observed during the remainder of the year. The surveys yield vital information on annual population changes and demographic parameters, such as sexual composition, age class structure, longevity, birth and survival rates, and reproductive performance of individual females. These data are crucial to determining population trends, analyzing threats, and studying population viability.

1.2 Maintain a current photo-identification catalog for the southern residents and expert staff able to photographically identify the whales.

The photo-identification catalog for the southern residents is an integral part of identifying individual whales during annual censuses and other encounters throughout the year, and should be maintained as a long-term resource. The Center for Whale Research has managed the catalog since 1976. It is equally important to keep at least one expert skilled in photographic identification of individual whales on the staff of the organization or agency holding the catalog.

1.3 Standardize the results of annual population surveys.

Small discrepancies exist in the annual count results used by different agencies and organizations. The results should be reviewed and standardized dating back to the 1970s to eliminate minor confusion among users. Refinement of data on births and deaths will improve population modeling and demographic analyses.

2. Protect the southern resident killer whale population from factors that may be contributing to the decline or reducing ability to recover.

Throughout the process to designate the southern resident stock as depleted, NMFS has received information on factors that may be contributing to the population decline. The primary potential risk factors for southern residents are prey availability; pollution and related effects, and; noise and stress associated with vessel activities. In 2003 and 2004, NMFS held a series of workshops focusing on these topics to identify management actions to consider in this plan. While some actions can be taken immediately based on current knowledge, others will require considerable research before effective management actions can be developed and implemented (Task 4.6).

2.1 Rebuild depleted populations of salmon and other prey to ensure an adequate food base for conservation of southern residents.

Over the past several decades, populations of salmon throughout the West Coast have declined. In 1991, NMFS began a comprehensive review of the status of salmonid populations throughout Washington, Oregon, Idaho, and California. NMFS identified Evolutionarily Significant Units (ESUs) of Pacific salmon and steelhead and 26 have been listed as endangered or threatened species under the ESA. These population declines are the result of numerous habitat-affecting factors (such as economic development, resource extraction, and other land uses), harvest practices, hatchery production and other factors. Comprehensive, focused recovery efforts are underway by a variety of groups in the region and NMFS is developing recovery plans for ESA listed species. NMFS recovery planning efforts are grounded in the many state, regional, tribal, local and private conservation efforts already underway throughout the region (NMFS Report to Congress, Northwest Salmon Recovery, Integrating Habitat, Hydropower, Harvest and Hatchery Programs with State/Federal/Local Recovery Efforts, 2004). Although the importance of specific salmon runs to southern resident killer whales has yet to be identified (Task 4.2), all of the salmon recovery efforts in Puget Sound and along the west coast will play an important role in addressing threats for the entire ecosystem, including fish and killer whales. As more is learned regarding the specific interactions between salmon and killer whales, the needs of southern residents will lend support to salmon recovery efforts.

2.1.1 Support local recovery efforts.

NMFS has eight geographic domains for recovery planning for salmon in WA, OR, ID and CA (http://research.nwfsc.noaa.gov/trt/index.html). NMFS formed two scientific groups to guide the technical elements of recovery planning in each domain. The Recovery Science Review Panel oversees the scientific components of the recovery planning process across the region, and ensures consistency in the technical approaches used across domains. The Technical Recovery Teams were appointed to each domain to identify biological recovery goals and delisting or viability criteria for the ESU. Recovery plans will be the result of a collaborative approach in each watershed about what actions are necessary and meet the legal, social, and cultural goals agreed on by people in the region. The WA state recovery goal is to "restore salmon, steelhead and trout populations to healthy harvestable levels and improve those habitats on which the fish rely." The Puget Sound Shared Strategy is one of five regional initiatives in Washington State to prepare recovery plans that gain regional support for measurable fish population recovery targets, integrate actions necessary in harvest, habitat and hatcheries, and gain commitment to achieve results.

Shared Strategy (www.sharedsalmonstrategy.org) engages local citizens, tribes, technical experts and policy makers to build practical, cost-effective recovery plans endorsed by the people living and working in the watersheds of Puget Sound. The Shared Strategy builds on existing efforts by local governments, watershed groups, and various entities already working on salmon recovery planning through a multitude of planning processes. NMFS and U.S. Fish & Wildlife Service (USFWS) and are active participants in the Shared Strategy.

In the Columbia River Basin, there is another example of ongoing regional recovery efforts. The state of Washington recently transmitted to NMFS a recovery plan developed by the Lower Columbia Fish Recovery Board (LCFRB) for the Washington portion of the listed Lower Columbia ESUs. NMFS will publish a Federal Register notice announcing a public comment period on this plan and laying out how the LCFRB plan meets the ESA statutory requirements and how NMFS proposes to fill any gaps.

These regional consensus processes will ensure that recovery plans ultimately reflect local needs and priorities while NMFS will ensure that the plans meet ESA requirements. The recovery plans will also ensure that habitat, hatcheries, hydropower and harvest management actions complement each other to restore naturally sustainable salmon populations to harvestable levels. Coordination of salmon and killer whale recovery efforts will benefit both efforts and the ecosystem. Additional information regarding the diet and distribution of southern resident killer whales (Task 4.1, 4.2) will help identify priorities and provide support for ongoing salmon recovery efforts.

2.1.2 Use NMFS authorities under the ESA and the MSFCMA to protect salmon habitat and regulate salmon harvest.

Habitat and harvest issues are important components of salmon recovery efforts. In addition to the recovery planning process, measures to protect habitat and regulate harvest are implemented through section 7 consultations and Section 10 permits under the ESA and through Fishery Management Plans (FMPs) under the

Magnuson Stevens Fishery Conservation and Management Act. Section 7 of the ESA requires Federal agencies to ensure, through a consultation process, that any action they authorize, fund, or carry out is not likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of their critical habitat. Critical habitat designations have been proposed for endangered and threatened species of salmon. Section 10 of the ESA provides for permits and exemptions for otherwise prohibited activities. To issue permits for activities including research, hatchery and harvest programs, NMFS must find that the taking will not appreciably reduce the likelihood of the survival and recovery of the species in the wild. In addition to development of biologically-based FMPs that ensure the conservation and recovery of listed ESUs, the MSFCMA also includes procedures designed to identify, conserve and enhance Essential Fish Habitat for species regulated under FMPs.

2.1.3 Consider effects on southern resident killer whales in managing hatcheries.

Hatchery and Genetic Management Plans (HGMPs) are a mechanism for addressing the effects of artificial propagation activities on certain listed species. NMFS uses the information provided by HGMPs in evaluating impacts on salmon listed under the ESA and in some cases in evaluation and issuance of section 10 permits. Completed HGMPs may also be used for regional fish production and management planning by federal, state, and tribal resource managers. As more is learned regarding the specific interactions between salmon and killer whales (Task 4.2), hatchery management practices can include consideration of effects on killer whales. Alterations in run timing and considerations of contaminants in hatchery fish are all potential hatchery practices that could be adjusted to benefit southern resident killer whales.

2.2 Minimize pollution and chemical contamination in southern resident habitats.

Chemical contamination represents another major threat to southern resident killer whales, despite the enactment of modern pollution controls in recent decades, which have been successful in reducing the presence of many contaminants in the environment. Recent studies have documented high concentrations of PCBs, DDTs, and PBDEs in southern resident whales. These and many other chemical compounds are of concern because of their ability to induce immune suppression, reproductive impairment, and other physiological damage, as observed in other marine mammals. Contaminants enter marine waters and sediments from numerous sources, but are typically concentrated near areas of high human population and industrialization. Freshwater contamination is also of concern because of its impacts on salmon populations during sensitive life stages. Because of projected human population growth in the region in coming decades, especially in Puget Sound and the Georgia Basin, greater efforts will be needed by governments, industry, and the public to minimize pollution. International coordination with Canadian efforts and broader international initiatives can also contribute to a cleaner environment. The Puget Sound Action Team (PSAT) coordinates and implements

Washington State's environmental agenda for Puget Sound. Actions to identify and stop pollution in the greater sound area are the primary focus of the 2005-2007 Puget Sound Conservation and Recovery Plan (Puget Sound Action Team 2004). Extensive background on contaminant regulations in British Columbia and needs for cleanup, research, and management in the Georgia Basin appears in Garrett (2004).

2.2.1 Clean up contaminated sites and sediments.

Many contaminated locations have undergone remediation since the 1970s and some are now considered cleaned. Continuation of remediation efforts remains an important priority for protecting the southern residents and prey species. The long-range goal of this work is to clean up all sites exceeding recognized government standards for pollution that may be contributing to the contamination of the whales or their prey. Necessary actions are discussed in greater detail in other planning documents (e.g., Puget Sound Water Quality Action Team 2000).

2.2.1.1 Identify and prioritize specific sites in need of cleanup.

Continued assessments are needed to identify and monitor contaminated marine sediments and upland sites in Puget Sound, the Georgia Basin, and other areas occupied by the southern residents and their prey. Comprehensive inventories of contaminated sites should be maintained and regularly updated, and should be used to prioritize sites in need of further investigation and remediation. A GIS project to identify and map contaminated sites is currently underway to assist with prioritizing cleanup based on importance for killer whales.

2.2.1.2 Remediate sites in need of cleanup.

Cleanup actions are ongoing at numerous contaminated locations in the region and should continue until completion. Remediation of sites that have yet to be cleaned will also be needed. In both cases, site-specific cleanup plans require regular re-evaluation, updating and may require identification of additional funding sources. Common methods for dealing with contaminated sediments and soils include capping, removing, and treating, but some areas can be left to naturally recover without remediation if the sources of contamination are controlled.

2.2.2 Minimize continuing inputs of contaminants into the environment.

Conventional pollution control practices have greatly improved in North America during recent decades, yet much remains to be done in reducing the environmental inputs of a wide diversity of chemical compounds that are potentially harmful to the southern residents and their prey. Mitigation activities should be conducted at the local, state, provincial, national, and international levels.

2.2.2.1 Minimize the levels of contaminants discharged by industrial and municipal sources of pollution.

Industries and municipal sewage treatment plants, commonly referred to as "point sources," produce vast amounts of wastewater, which can be a significant source of contamination when insufficiently treated. Important point sources of contamination in the region should be identified (Task 4.6.3.3) and prioritized for action. Needed activities include adoption of revised water and sediment quality standards as needed, requiring discharge permits to cover all pollutants of concern, upgrading treatment systems and pretreatment programs, improving permit compliance through inspections and enforcement, and elimination of unpermitted discharges (Puget Sound Water Quality Action Team 2000).

2.2.2.2 Minimize the levels of contaminants released by non-point sources of pollution.

Non-point source pollution is another primary contributor of contamination in aquatic environments and originates from poor agricultural and forest practices, stormwater runoff, improper disposal of household hazardous wastes, certain recreational boating activities, failing septic systems, improper use of pesticides, and atmospheric deposition. Pollution from some of these sources is considered a major impairment of freshwater and estuarine salmon habitat in the region. Although water quality standards and management plans already exist to reduce pollution from non-point sources, government agencies and the public can do more to meet goals through education, financial and technical assistance, regulation, enforcement, and improved watershed planning, and implementation of best practices (Puget Sound Water Quality Action Team 2000, Garrett 2004). Water quality monitoring should continue. International agreements designed to curb certain types of pollutants, especially atmospheric pollutants, should be considered.

2.2.2.3 Develop environmental monitoring programs for emerging contaminants.

Southern resident killer whales and their prey may be impacted by numerous emerging chemical compounds entering the environment, including brominated flame retardants (BFRs), polychlorinated paraffins (PCPs), perfluorooctane sulfonate and other perfluorinated compounds, polychlorinated naphthalenes (PCNs), polychlorinated terphenyls (PCTs), and endocrine disruptors (e.g., synthetic estrogens, steroids, some pesticides, and personal care products) (Grant and Ross 2002). Monitoring programs for these chemicals should be developed or expanded (Garrett 2004). New regulations pertaining to discharge may also be needed.

2.2.3 Minimize contamination in prey.

Additional research is necessary to identify prey species of southern residents and monitor contaminant levels in prey (Tasks 4.2 and 4.6.1.2.) to evaluate the most effective methods beyond Tasks 2.2.1 and 2.2.2 in minimizing contamination in prey. In particular, there is a strong need to evaluate the role of current hatchery rearing practices that encourage longer residency periods in Puget Sound by chinook salmon.

2.3 Minimize disturbance of southern resident killer whales from vessels.

An increasing number of vessels around the whales was identified as a potential risk factors in the recent decline of southern residents, however, the relative importance of these concerns is not well understood. Human-generated noise has the potential to mask echolocation and other signals used by the species, as well as to temporarily or permanently damage hearing sensitivity, whereas vessel presence has been implicated in increased energy expenditure for whales (Foote et al., 2004). Vessel strikes are rare, but are a potential source of injury or mortality and should be monitored. Land-based viewing sites, voluntary no-boat zones, approach guidelines and education programs (Task 5.2) have been developed to address vessel pressure on the southern residents, but additional management measures may be necessary to reduce vessel effects. Further information on effects, such as vessel emissions and potential actions, such as vessel quieting technology, will guide future recommendations on other potential impacts from vessels. Ambient air monitoring near whale-watching craft would help determine whether the southern residents may inhale significant amounts of potentially harmful airborne pollutants, such as polycyclic aromatic hydrocarbons (PAHs), emitted by engine exhausts.

2.3.1 Monitor non-military vessel activity around whales.

2.3.1.1 Expand efforts to monitor commercial and recreational whale-watching vessels.

Two on-water stewardship programs, Soundwatch and the Marine Mammal Monitoring Project (M3), currently monitor commercial and recreational vessels engaged in whale watching in the vicinity of the San Juan Islands and southernmost British Columbia. In addition to educating boaters about the “Be Whale Wise” guidelines for viewing whales, the programs document levels of boating activity near the whales and monitor vessel compliance with the guidelines. These programs should be expanded to allow daily coverage of primary viewing areas during the main viewing season (i.e., May to October), longer hours of coverage per day, and compilation of more complete whale-watching data. Continuation of current programs and additional efforts will assist in assessing impacts of vessels on whales and evaluating future guidelines, regulations or protected areas.

2.3.1.2 Evaluate the relative importance of shipping, ferry, fishing, research, and other vessel traffic to disturbance of killer whales (Task 4.6.2.1).

Numerous types of vessels have the potential to negatively affect the behavior of killer whales, but little information is available on this issue. The presence and activity patterns of non-whale-watching vessels in the vicinity of southern resident and other killer whales should be monitored and evaluated (Task 4.6.2.1) to determine their potential effect. needed.

2.3.2 Continue to evaluate and improve voluntary whale-watching guidelines.

There is a continual need for private boaters to be educated on boating practices in the vicinity of killer whales. The "Be Whale Wise" education campaign is a successful international program and was created with input from government, commercial and private organizations. In addition to the "Be Whale Wise" whale watching guidelines, the Whale Watch Operators Association Northwest have adopted a more comprehensive set of guidelines for use by commercial vessels. Guidelines should continue to be refined as more is learned about the impacts of vessels on killer whales (Task 4.6.2) and shared to better inform the public and industry about how to view whales without affecting them.

2.3.3 Evaluate the need to establish regulations regarding non-military vessel activity in the vicinity of whales.

Regulations have been established for several ESA-listed species of whales in sensitive areas (e.g., humpback whales in Alaska and Hawaii, and northern right whales in the northwest Atlantic) to protect them from vessel impacts. Regulations regarding vessel activities, such as speed or approach distance, should be evaluated to augment the guidelines and increase enforceability to protect southern resident killer whales. Regulatory mechanisms should be supported by research (Task 4.6.2) to ensure suitability for the whales and coordinated with enforcement to foster effectiveness with the public.

2.3.4 Evaluate the need to establish areas with restrictions on non-military vessel traffic.

There are a variety of options to address vessel activity in sensitive areas for southern residents, including fixed seasonal restrictions, restrictionss when whales are present, or restrictions for whale watching vessels only. Commercial operators and many private boaters already voluntarily adhere to the voluntary closure of an area off western San Juan Island that is used preferentially by the whales for feeding, traveling, and resting. Evaluating this site will help to determine if area vessel restrictions are effective and whether additional voluntary or mandatory areas should be established. Criteria for selecting areas should be supported by research on habitat use (Task 4.8) and vessel impacts (Task 4.6.2).

3. Protect the southern resident killer whale population from additional threats with the potential to cause disturbance, injury, or mortality, or impact habitat.

The following issues were not identified as major risk factors in killer whale decline, however, they have been identified as potential factors that can be addressed to protect killer whales. For the most part, these factors are rare and unpredictable and may have variable effects depending on exposure, magnitude of event, and number of animals present. In some instances management measures are already in place to mitigate and reduce the possibility of injury or mortality. Many activities where impacts on protected resources may occur are addressed through incidental harassment authorizations under MMPA.

3.1 Minimize the risk of oil spills.

Major oil spills are potentially catastrophic to the southern resident population, either through direct mortality or from harmful physiological effects, as shown by the significant declines in two groups of Alaskan killer whales that likely resulted from the *Exxon Valdez* spill in 1989. Despite many improvements in spill prevention since the late 1980s, much of the region inhabited by the southern residents remains at risk from serious spills because of its heavy volume of shipping traffic and its role as a leading petroleum refining center. Chronic small-scale oil pollution originating mainly from routine shipping practices is also of concern because of its cumulative long-term impacts on aquatic food webs.

3.1.1 Prevent oil spills.

Existing state, provincial, federal, and international programs (e.g., Pacific States/British Columbia Oil Spill Task Force) for preventing spills should be fully supported and new spill prevention policies should be developed and implemented, as appropriate. High priority needs for reducing the risk of marine spills include the continued conversion of shipping fleets to vessels with safer designs, improved salvage and rescue capabilities, improved operating standards at oil handling facilities and aboard vessels, prevention of pipeline spills near marine areas, prevention of waste oil dumping from vessels, and greater enforcement. Permanent funding is needed for the year-round deployment of a rescue tug at Neah Bay, Washington. Continued use of tanker escort tugs should also be required. Steps for reducing the occurrence of smaller spills include improved operating standards aboard vessels, at ports, and at oil handling facilities in compliance with MARPOL, and greater enforcement.

3.1.2 Prepare for and respond to oil spills to minimize their effects on southern resident killer whales.

Oil spills should be cleaned up as rapidly as possible to minimize their impacts on the whales. Much better contingency planning, more training, and frequent re-evaluation of response efforts are needed to improve responses to future spills. Recent reviews of response efforts have identified needs for greater standardization of response procedures, more aggressive initial responses, better interagency coordination, additional cleanup equipment to be stationed throughout the region, procurement of improved spill detection equipment, increased targeting of sensitive habitats during cleanup efforts, and greater reliance on geographic response plans.

3.1.3 Develop strategies to deter killer whales from entering spilled oil.

The use of netting, acoustic harassment devices, and other determent methods (see Petras 2003) should be evaluated as possible techniques for keeping southern resident and other killer whales away from spilled oil. If effective methods can be found, deployment strategies for use during spills should be developed and incorporated into oil spill response planning. Appropriate determent methods may vary with spill size, location, and other circumstances.

3.2 Reduce the risk of infectious diseases in southern resident whales.

Gaydos et al. (2004) identified a number of virulent diseases that are potentially transmissible to the southern resident population, with morbillivirus, brucellosis, and cetacean pox virus being of greatest concern. Evidence of exposure to some of these pathogens has been detected in other marine mammal populations in or near the range of the whales. The Southern Resident community is vulnerable to a serious disease outbreak because of its high degree of sociality, smaller population size, and seasonal concentration near the San Juan archipelago. High contaminant levels may also contribute by compromising immune function, thereby increasing disease susceptibility. Activities to prevent diseases in the population are fairly limited. Efforts to monitor diseases in the whales and sympatric marine mammals should continue (Task 4.6.5 and Task 6). This will provide a better understanding of the role of disease in these populations and may alert scientists to outbreaks, perhaps allowing novel control responses to be devised. To minimize the potential for introducing new infectious diseases, complete disease screenings should be conducted on any whales translocated into the region prior to their being moved. The southern residents are also potentially vulnerable to several largely terrestrial diseases, such as toxoplasmosis and canine distemper virus (Wiles, 2004). Improvements in managing sewage outflows, animal waste, agricultural runoff, and certain land use practices may help prevent the introduction of such pathogens into southern resident habitats.

3.3 Continue to use established MMPA mechanisms, such as incidental harassment authorizations, to minimize any potential impacts from human activies involving acoustic sources, including Navy tactical sonar, seismic exploration, and other sources.

The majority of requests for incidental harassment authorizations under the MMPA involve the incidental harassment of marine mammals by noise. Killer whale hearing ranges from 1 to 120 kHz (with peak sensitivity from 20 to 50 kHz, Szymanski et al. 1999) which fully covers the bandwidth generally considered as mid-frequency (2 to 10 kHz). Threshold levels at which underwater anthropogenic noise adversely affects behavior and hearing are poorly understood. In other cetaceans, the onset of temporary hearing loss has been estimated to occur at received sound pressure levels of 195dB at 1 sec duration exposures (Schlundt et al. 2000). Avoidance behaviors in a range of species exposed to different sound source, other than mid-frequency sonar, have been observed at received levels of 140-160dB (Malme et al. 1983, 1984, 1988, Ljungblad et al. 1988, Tyack and Clark 1998). Effects of noise on killer whales depend on sound frequency, exposure level, and duration, as well as distance from the source, geographical features, and the animal's hearing ability, exposure history, and motivational state. Additional acoustic monitoring and research on the effects of noise exposure are important to evaluate potential impacts from acoustic sources (Tasks 4.6.2.2, 4.6.2.3, and 4.6.2.4).

3.4 Reduce potential for impacts of invasive species in southern resident habitats.

Invasive species have the capacity to greatly alter ecosystem functions and food webs, and therefore pose a major threat to many rare or declining native species. Invasive species are not currently known to affect southern resident killer whales, but there is significant potential for serious negative interactions from future introductions, especially through impacts on prey. Several hundred non-native species already exist in marine and estuarine areas of the whales' range (P. Heimowitz, pers. comm.), including at least 95 species in Washington and British Columbia (Meacham 2001). Further introductions are inevitable, but greater vigilance and preventive management actions can reduce their incidence.

3.4.1 Prevent the introduction and spread of invasive species.

It is far more practical to prevent new introductions of non-native species than to undertake control efforts after invasive populations are detected. Non-native marine and estuarine species are commonly introduced or spread through the discharge of ballast water in ships, hull and anchor fouling, boater activity, and occurrence in shipments of shellfish and fish. Many federal, state, and provincial regulations and programs are already in place to limit invasives, but should be revised or expanded, as needed. Many suggested management activities pertaining to aquatic invasive species in Washington and Oregon appear in Meacham (2001) and Hanson and Sytsma (2001). Continued monitoring for wild Atlantic salmon populations in the region is an important priority, but detection programs for other species are also needed (Cohen 2004). The Western Regional Panel on Aquatic Nuisance Species can be used to coordinate activities among jurisdictions.

3.4.2 Eradicate existing populations of invasive species.

Few tools or strategies are available for the management and control of invasive species in unconfined marine and estuarine habitats, which makes eradication nearly impossible for many species. Nevertheless, such programs may be practical for some species and should be attempted when favorable circumstances exist. Control efforts for marine invasives are usually costly and manpower intensive.

4. Conduct research to facilitate and enhance conservation efforts for southern resident killer whales.

   Long-term studies of the southern residents include unprecedented data on the individual whales in this small population. However, many important gaps in our understanding of these whales still exist, and substantially more research is required to address critical questions pertaining to their general biology and to address conservation concerns. Killer whales are inherently difficult to study for a variety of reasons, including their marine habits, large body size, intricate social structure, large geographic ranges, and long life span. In 2003 and 2004, funding was made available to expand the research and conservation of southern resident killer whales. Most of the research projects funded have been relatively inexpensive due to opportunistic approaches, small sample sizes, and reliance on both low-tech and non-invasive methods. However, future studies must begin to address some of the complex cause-and-effect relationships to determine the relative impacts of various extrinsic and intrinsic factors on southern resident whales, and will necessarily require the application of new techniques, the use of more sophisticated and costly technology, the collection of larger sample sizes, and for some, the use of moderately invasive methods (e.g., tissue sampling and telemetry). Long-term commitments of funding and support will be needed to sustain much of this work. Transboundary coordination is desirable in these efforts (Task 7.1).

   Research is necessary to better understand the effects of potential risk factors that have been linked to the recent decline of the southern residents. Study results will be an important resource for developing science-based management actions to address the threats. Many research tasks should involve repeated sampling efforts to monitor future trends and to assess the effectiveness of management actions.

   Outlined below are ten of the most critical research tasks, with subtasks, that should be addressed by future studies on the southern resident population. For many of these tasks, studies should ideally be designed to identify both similarities and differences among the three commonly recognized southern resident pods: J, K, and L. Current data have highlighted some interesting pod-specific demographic and distribution patterns, and future studies should be designed to identify factors that may be causing disproportionate declines in some pods. When appropriate, research results should be compared to similar data from other North Pacific killer whale populations, especially the northern residents and southern Alaskan residents, to gain a broader perspective on biological issues and risks to the southern residents. Studies of captive killer whales and closely related marine mammal species may also be useful, particularly on health-related issues, contaminants, and the development of techniques. For a number of topics, examination of archived data is recommended to compare past and present conditions. Many tasks necessitate repeated sampling efforts to monitor future trends and to assess the effectiveness of management actions.

4.1 Determine the distribution and movement patterns of the southern residents.

The population inhabits an extensive geographic range that is currently known to extend from northern British Columbia to central California. Movements are relatively well known during the warmer months of the year when the whales regularly occupy the protected inland waters of Washington and southern British Columbia, but are very poorly understood when the animals visit the waters of the Strait of Juan de Fuca and the outer coast.

4.1.1 Determine distribution and movements in outer coastal waters.

One of the highest research priorities is to document the population's use of offshore areas, where fewer than 25 sightings have been verified over a 30-year period. Considerable time is spent in this portion of the range, especially during the winter and early spring, although ranging patterns vary by pods. Information is needed on areas of regular occurrence, movement patterns, and distances traveled offshore.

4.1.2 Improve knowledge of distribution and movements in the Georgia Basin and Puget Sound.

Much remains to be learned about distribution and movements in inland waters, especially for individual pods and matrilines. Such information will be useful for identifying interpod differences in range, diet, habitat use, and threats; changes in range use over time; and areas worthy of special protection.

4.1.3 Determine the effects of prey abundance and availability and other factors on whale distribution and movements.

Southern resident whales display extensive seasonal and sometimes daily travel patterns. As diet becomes better understood, researchers should investigate and clarify the influences that prey abundance, quality, and availability have on the population's distribution and movements, both currently and historically.

4.2 Investigate the diet of the southern residents.

Many aspects of diet are poorly known for the population and require study. Such information will shed light on many vital issues, including potential contaminant sources and whether prey abundance is sufficient to support the population. Whenever possible, pod-specific and matriline-specific diet preferences should be identified to enable assessment of fine-scale dietary preferences.

4.2.1 Determine the diet of the southern residents.

Another urgent priority is to identify the year-round food habits of the southern residents in all parts of their range. Salmonids, especially chinook, are generally thought to be important prey. However, prey selection likely varies both in time and space. Therefore additional dietary information is needed to confirm the relative importance of chinook and to identify the contributions of other prey, including different salmon species, groundfish, herring, and squid. Information on preferred prey size, annual variation in diet, and prey selection by age and sex class of whale in relation to species availability is also of interest.

4.2.2 Determine the importance of specific prey populations to the diet.

Seasonal salmonid runs from particular river systems likely play a large role in the diet and distribution of the southern residents, but researchers have thus far failed to correlate whale occurrence with the presence and availability of any specific prey population. Identifying prey populations of special significance to the whales is needed (Task 2.1).

4.2.3 Determine the extent of feeding on hatchery fish.

Hatchery fish comprise a large portion of salmonid populations in much of the range of the southern residents, but few data exist on their importance to the whales' diet. This should be established because the characteristics (e.g., energy content and contaminant loads) of hatchery salmon may differ somewhat from those of wild salmon. This information may also help evaluate whether future changes in hatchery management and production levels will impact the whales.

4.3 Analyze the population dynamics of the southern residents.

The population history and maternal genealogy of the southern residents are completely known for individual whales born after 1974. Existing studies of these data (Olesiuk et al. 1990, Krahn et al. 2002, 2004a) have been quite useful in describing the dynamics of the population, but efforts should be expanded to provide more comprehensive analyses. This information will provide greater insight into the processes affecting the southern resident population, especially during periods of decline, and will improve the accuracy of future population viability analyses. Demographic comparisons should be made among pods and with other resident populations.

4.3.1 Determine causes of mortality.

Definitive causes of death have not been established for any of the nearly 80 southern residents that have died since 1974. This is largely due to the lack of carcasses for necropsy and difficulties in distinguishing direct causes of death (e.g., starvation and disease) from indirect factors impacting health (e.g., contaminant burdens, food limitations, and vessel interactions). Necropsies to determine causes of mortality for all age and sex classes should be conducted on all available carcasses (Task 6.2.3).

4.3.2 Evaluate survival patterns.

Mortality rates may be one of the most important factors affecting population changes in killer whales. Comprehensive studies of mortality patterns and associated influences are therefore needed for the southern residents. Two high priority tasks are to determine the reasons behind the alternating 7-year periods of higher and lower mortality in the population, and L pod's disproportionately higher death rate since the mid-1990s.

4.3.3 Evaluate reproductive patterns.

Reproductive patterns also affect population trends and should be described in detail for the southern residents. Major influences on birth rates and reproductive trends should also be investigated. Areas of particular interest include the reasons for 1) the population's cyclic periods of higher and lower birth rates, 2) its longer mean interval between births of viable calves, as compared to other resident populations, and 3) L pod's poor calf production during the past decade, and 4) temporal trends of sex-bias in the production of calves. In addition, identification of factors causing poor reproductive success in females is also important. Increased monitoring of the population during the winter and spring will allow researchers to better determine true birth rates for the population.

4.3.4 Evaluate population structure.

More detailed analyses of age and sex structure in the southern resident population are needed to assess threats and determine effects on population stability. The causes of changes in population structure should also be identified.

4.3.5 Evaluate changes in social structure.

Highly stable matrilines are a major feature of southern resident biology. Detailed assessments of social structure dynamics should be made to search for evidence of potential stresses on the population and to examine effects on population stability. Evaluation of the impacts of reduced population size on social structure is also needed. One particular topic deserving study is the consequences of the losses of key individuals from the population, particularly matriarchal and post-reproductive females, which could result in reduced alloparenting and loss of long-term cultural knowledge, thereby lowering population fitness.

4.4 Investigate the health and physiology of the southern residents.

Knowledge of individual health and physiology of the species is beneficial in evaluating a population's status, dynamics (e.g., survival and fecundity), and threats. Both topics require much additional study for the southern residents.

4.4.1 Assess the health of population members.

Hormone levels, blubber depth, respiratory conditions, reproductive status, and other aspects of physical condition should be assessed in sufficient numbers of individual whales representing particular age and sex classes to evaluate the population's health. Evaluations should be done through the application of proven biopsy sampling methodologies, or the application of emerging health-monitoring techniques (e.g., collection of respiratory gases, blowhole residues, and fecal samples, or use of ultrasound) that do not require the physical restraint or capture of animals.

4.4.2 Assess growth rates.

Growth rate comparisons among different cohorts of calves may offer another way of evaluating the effects of changing environmental conditions on the southern residents. This work will require the development of suitable morphometric indices. Dorsal fin measurements, which are obtainable from photographs taken during regular population monitoring, may achieve this need and have the added benefit of being retrievable from photos archived since the 1970s.

4.4.3 Determine metabolic rates and energy requirements.

Studies of captive killer whales have provided limited data on the species' energy demands, but may not accurately reflect the needs of the southern residents. Knowledge of year-round metabolic rates and caloric requirements of different age and sex groups will help determine whether critical periods of the year exist when adequate prey levels are unavailable. Physiological indicators of nutritional stress should also be developed.

4.5 Investigate the behavior of the southern residents.

Comparisons of behavioral data are potentially valuable for evaluating changes in activity patterns over time that may indicate stresses on the population. Information on numerous behaviors (e.g., foraging, socializing, traveling, resting, diving, vocalizations, responses to vessels, and habitat selection) should be collected year-round and analyzed at the individual and group levels, and when possible compared with past data. Consistency and coordination of behavioral data collected by different researchers will assist with comparisons. Other needs include further clarification of the contexts of different behaviors and determination of nighttime activity patterns.

4.6 Assess threats to the southern residents.

Southern resident whales face a number of threats, with reduced prey abundance, excessive marine noise and vessel interactions, and elevated contaminant burdens usually cited as the most serious conservation concerns (Task 2). Additional research is needed to characterize these problems and their effects on the population, and to identify other possible extrinsic factors affecting it. One goal of this work should be to determine whether synergistic effects are occurring, whereby multiple factors act in combination to harm the whales. Whenever possible, research activities should assess threats at the level of the pod or matriline to examine pod-specific exposure to the identified threat factors.

4.6.1 Assess the effects of changes in prey populations.

Human activities have profoundly altered populations of salmon and other southern resident prey during the past 150 years. The role that changes in prey abundance, availability, and quality have played in past declines of the whales or are currently limiting population growth requires further study.

4.6.1.1 Determine historical changes in prey occurrence and their effects on southern resident population dynamics.

Collection of data and comprehensive assessments of past and present prey abundance and availability are needed throughout the southern resident's range at both regional and watershed scales. These data should be used to understand the role that changes in prey populations may have had on the whales' population dynamics. With improved information on dietary preferences, efforts can be focused on current favored prey species, but a broad perspective is also desirable to consider other prey that may have been formerly important to the whales.

4.6.1.2 Assess changes in prey quality and their effects on southern resident population dynamics.

Better data are needed on body condition traits (e.g., size; age; caloric, fat, and nutrient content; and contaminant burdens) of important prey. Such information should be gathered for a variety of prey subcategories, including different populations and age groups within a species, and wild versus hatchery fish. When possible, these studies should make inferences on changes in body condition between past and present prey populations. This information should be used to consider potential impacts on southern resident health and population dynamics.

4.6.1.3 Determine whether the southern residents are limited by critical periods of scarce food resources.

Information on the whales' distribution, movements, diet, foraging behavior, and physiology and changes in prey abundance, availability, and quality should be collected and analyzed to determine whether the southern residents face critical periods when food resources limit the population, either annually or more infrequently.

4.6.1.4 Assess threats to prey populations of the southern residents.

Research should continue on a variety of known threats affecting populations of salmon and other prey species, including loss and alteration of spawning and rearing habitat, overharvest, pollution, food limitations, and hatchery impacts. The role of salmon aquaculture in transmitting sea lice to free-ranging salmon needs further evaluation, as do threats posed by invasive species, such as Atlantic salmon, cordgrass, and invertebrates that may disrupt food chains for salmon. The potential for diseases to cause significant changes in prey populations should also be monitored.

4.6.2 Assess the effects of human-generated marine noise and vessel traffic.

The southern residents are exposed to increasing levels of marine noise and vessel traffic over much of their range, and in inland waters, high levels of commercial and recreational whale watching. Excessive noise from vessels and other anthropogenic sources may interfere with the whales' communication, foraging, and navigation, may increase daily energetic costs, and may produce physiological trauma. Vessel presence is also potentially problematic under some circumstances and may inhibit important behaviors. There is an urgent need for greater study of the impacts of marine noise and vessel interactions. Research on northern resident whales may be helpful in testing some hypotheses, but not all findings can be extrapolated to the southern residents.

4.6.2.1 Determine vessel characteristics that affect the southern residents.

Research is needed to evaluate which vessel traits, such as vessel type and activity, noise level, distance, size, speed and direction of travel, duration of interaction, and density and number of vessels present, may cause changes in the whales' behavior. Studies should focus both on commercial and private whale-watching craft, as well as commercial fishing vessels, ferries, and all other vessel types commonly encountered by the whales either for prolonged periods, or in high numbers. Investigations should attempt to determine whether problems caused by vessels are largely acoustic or non-acoustic in nature. Numerous study methods can be employed, but the use of controlled experiments, and land- and boat-based observations and acoustic techniques are particularly appropriate.

4.6.2.2 Determine the extent that vessels disturb or harm the southern residents.

Studies should resolve whether interference from whale-watching craft and other vessels cause significant behavioral changes or physical injuries among the whales, and if so, whether these effects are serious enough to reduce survival or reproduction in the population. Threshold levels at which impacts occur should also be established. (Task 3.3) Data on vessel numbers and activity should be compiled for the entire distribution of the southern residents. The Whale Museum and Soundwatch have gathered whale-watching statistics for the Georgia Basin and Puget Sound since the 1980s, including the size of the commercial fleet, the amount of viewing activity by commercial and private craft, and infractions of whale-watching guidelines. These efforts should be continued so that future trends in viewing pressure can be evaluated and perhaps correlated with changes in the southern resident population.

4.6.2.2.1 Determine the effects of vessels on foraging and other behavior.

Assessments of impacts on foraging efficiency and energy acquisition, and whether energy expenditures increase in the presence of vessels are particularly needed, but possible changes in the occurrence of other necessary behaviors such as resting, socializing, and parental care also require evaluation. Additional topics to be addressed are whether cumulative effects on behavior appear over time (e.g., during the course of the whale-watching season) and whether the whales display any habituation to vessel presence.

4.6.2.3 Determine the extent that other sources of noise disturb or harm the southern residents.

The southern residents are exposed to numerous other sources of marine noise, such as military and non-military sonar, seismic testing, and marine construction. The impacts of these sounds on the behavior and health of the whales should be assessed.

4.6.2.4 Determine the acoustic environment of the southern residents.

Little information exists on the types and levels of marine noise to which the whales are exposed. Inventories of acoustic conditions are needed throughout the range of the southern residents, but especially in areas of high vessel traffic, such as the San Juan Islands. Studies of noise production by vessels and ambient sound conditions are the highest priority, but other noise sources should also be described. Historical trends in noise levels should be estimated as well. An additional need is to examine the characteristics of sound propagation in the areas used by whales.

4.6.2.5 Determine the hearing capabilities and vocalization behavior of the southern residents near noise sources.

Noise from vessels and other sources may impair the hearing abilities of killer whales, thereby masking important signals associated with communication, foraging, and navigation. Better information is required on the critical distances that the southern residents need for these activities and whether the whales are able to partially compensate for masking noise. Acoustic responses to noise, including changes in the composition, rates, lengths, and "loudness" of calls, also require evaluation. For example, Foote et al. (2004) reported that call duration of the southern residents increased over time as the number of whale-watching vessels increased in the area.

4.6.2.6 Assess the effects of human-generated marine noise on southern resident prey.

Fish are also considered vulnerable to intense underwater sounds. Increased levels of background noise can mask sounds critical to fish survival, decrease auditory sensitivity, and modify behavior. Research is needed to determine whether prey populations change their behavior in response to anthropogenic noise, making the capture of individual fish more difficult for the southern residents.

4.6.3 Assess the effects of contaminants.

Southern resident whales carry high concentrations of PCBs and likely have rapidly increasing levels of PBDEs, making them by far the most contaminated resident killer whale community in the northeastern Pacific. The sources of these and other chemical pollutants in the whales are unknown, but probably stem in part from the population's occurrence in the heavily developed Georgia Basin and Puget Sound during much of the year. It is essential to learn more about the contaminant burdens carried by the whales, their impacts on the population, and levels of exposure.

4.6.3.1 Determine contaminant levels in the southern residents and other killer whale communities in the northeastern Pacific.

Two studies (Ross et al. 2000, Rayne et al. 2004) have described concentrations of PCBs, PCDDs, PCDFs, PBDEs, PBBs, and PCNs in live southern resident whales, but were based on a small number of biopsy samples collected from 1993-1996. Updated and expanded tissue sampling of more members of the population is needed to obtain contaminant trend information and to examine differences among individuals whales, age and sex categories, pods, and birth order rankings. Continued periodic sampling and testing for a broader range of compounds are strongly recommended. Tissue sampling of stranded individuals should also continue. Sampling of other regional killer whale populations may help clarify the sources of contaminants.

4.6.3.2 Determine contaminant levels in southern resident prey.

Relatively little information is available on pollutant concentrations in southern resident prey. Better data are needed for virtually all prey species to provide a greater understanding of exposure to the whales. Levels of contamination should be assessed for a variety of compounds and prey subcategories (see Task 4.6.1.2).

4.6.3.3 Determine the sources of contaminants entering southern resident prey.

Better data should be gathered on the pathways through which prey become contaminated. This work will require expanded assessment of pollutant levels in food webs and the general environment throughout the southern residents' distribution, and can be achieved through review of existing data sources and increased survey efforts. Estimates of inputs from specific point and non-point sources are needed. Monitoring of contaminant levels in biota at various trophic levels (e.g., harbor seals, harbor porpoises, other fish, and mussels) and sediments will provide essential information on spatial and temporal patterns of contamination across the region, including additional sites requiring cleanup or management (Task 2.2).

4.6.3.4 Determine the effects of elevated contaminant levels on survival, physiology, and reproduction in the southern residents.

Exposure to moderate to high contaminant concentrations has been linked to a number of negative health effects in marine mammals, including impaired reproduction, immunotoxicity, hormonal and enzyme dysfunction, and skeletal deformities. Studies are needed to establish whether the southern residents are experiencing similar physiological effects and whether these are influencing life history parameters and population trends. Factors (e.g., nutritional stress or age) that may exacerbate the impacts of contaminants should also be investigated.

4.6.4 Determine risks from other human-related activities.

A variety of other anthropogenic threats (e.g., oil and chemical spills, seismic testing, certain military activities, fisheries-related entanglements and interactions, direct persecution, and ship collisions) are potentially harmful to the southern residents (Task 3.5). Although programs such as the MMPA reporting system are already established for fishermen to report injuries and deaths of marine mammals (insert website), improved documentation and monitoring of a variety activities and any impacts on the whales are needed. Moreover, disaster response strategies developed for oil and chemical spills should include post-event tissue sampling to assess exposure and evaluate physiological responses (Task 3.1). This task will become especially relevant as more is learned about the outer coastal areas occupied by the population.

4.6.5 Evaluate the potential for disease.

A recent summary of disease threats to the southern residents identified several high priority pathogens warranting further study (Gaydos et al. 2004). Surveillance for these and other diseases should be expanded to cover all populations of killer whales and cetaceans in the northeastern Pacific (Task 3.2).

4.6.6 Determine the risk of inbreeding.

The southern residents may be at risk from inbreeding depression because of the population's small size. Only 28 breeding adults remain in the population, but effective population size is perhaps even smaller. Assessments are needed to determine if genetic diversity is decreasing over time, and to genetically determine the mating system of the population.

4.7 Identify important habitats for the southern residents.

These habitats include sites that are regularly visited for feeding and other necessary activities, as well as locations of importance to major prey species. Such sites can likely be determined by examining movement and distribution patterns and identifying areas of repeated use by both whales and their prey. Site visits to investigate reasons for use (e.g., foraging or other behavior) of specific locations may be needed, especially for offshore areas. The value of many important habitats to the whales will probably differ among pods and vary seasonally with prey occurrence. Habitat assessment is also necessary to propose critical habitat and evaluate potential sites for protected areas.

4.8 Determine the effects of variable oceanographic conditions on the southern residents and their prey.

Cyclic changes in climate trends across the North Pacific Ocean, such as the Pacific Decadal Oscillation, produce fluctuating oceanographic and atmospheric conditions that strongly affect ocean productivity and prey abundance. These changes presumably influence prey availability for the southern residents and therefore may affect the whales' survival, movements, and other life history traits. The consequences of changing oceanographic patterns on the population should be examined as more is learned about the biology of the whales and the biotic and abiotic effects of these climate regimes. Similarly, more information is needed on effects to prey populations. The influences of global climate change on regional climate regimes should also be evaluated.

4.9 Determine genetic relationships.

A better understanding of the genetic relationships within and among killer whale communities in the northeastern Pacific is needed to assess rates of gene flow and risk from inbreeding, and to solve taxonomic concerns affecting population management.

4.9.1 Determine paternity patterns in the southern residents.

Additional genetic analyses should be made to establish paternity in the southern residents. This will yield important information on the contribution of individual males in siring calves, and whether mating occurs strictly among the southern resident pods, or if genetic exchange is occurring with the neighboring northern resident and offshore populations. Such knowledge will help assess the risk of inbreeding in the southern resident population. Given the low numbers of mature males in J and K pods, it will also assist evaluations of recent patterns of reproductive success in L pod.

4.9.2 Determine genetic relationships among populations.

Better data are needed on the genetic relationships among killer whale communities in the northeastern Pacific to estimate rates of gene flow among groups and resolve taxonomic issues. Comparisons of physical and other biological parameters are also needed to resolve questions about the relationships between killer whale populations. This information will improve understanding of the degree to which the southern resident population is evolutionarily isolated and demographically closed.

4.9.3 Expand the number of genetic samples available for study.

Acquisition of a substantially larger set of tissue samples is an important priority for conducting future genetic analyses of the southern residents and other regional populations (Barrett-Lennard and Ellis 2001). Samples can be obtained using proven remote biopsy darting methods, and should be gathered from all or most of the southern residents. Priority should be given to sampling the oldest population members before these animals die.

4.10 Improve research techniques and technology.

Improvements in study methods and equipment will greatly benefit future research efforts and allow important long-standing questions to be answered. Needs include: 1) better methods for assessing the physical condition of animals, analyzing genetic and contaminant samples, evaluating diet and prey abundance, and conducting acoustic surveys, and 2) improved equipment for telemetry and other tagging studies, and acoustic surveys. Development of non-invasive techniques is especially desirable. In some cases, new techniques and technology should be tested on other species or non-threatened killer whale populations before application to the southern residents.

5. Develop public information and education programs.

Public attitudes are a major part of the success or failure of conservation efforts for most endangered species, especially those occurring near major population centers. Killer whales already enjoy widespread popularity among much of the public living in coastal regions of western North America, but much remains to be done to publicize the plight of the southern resident population and to discourage potentially harmful human activities.

5.1 Enhance public awareness of southern resident status and threats.

A number of tools and outlets are available to educate the public about the southern residents and their conservation. Each of the threats to the population will require an education and outreach component in order to improve the situation through changing people's behavior, expressing political will, and gathering community support for management initiatives. Government agencies can partner with a variety of existing private organizations to provide information to the public. Private conservation groups interested in the conservation of the whales can assist by including appropriate information in their publications and news releases.

5.1.1 Exhibits and programs at local museums, aquaria, and parks.

The Whale Museum, Seattle Aquarium, Vancouver Aquarium Marine Science Center, and Lime Kiln Point State Park have developed exhibits and other programs devoted to increasing public awareness about the biology, behavior, and conservation status of southern resident killer whales, as well as knowledge about marine ecosystems. Such displays and activities reach both local and visiting audiences and raise basic level of knowledge regarding the ecosystem and killer whales. New exhibits or and expansion of current programs will enhance capabilities to reach new and larger audiences.

5.1.2 School programs.

Several education programs targeted at teachers and students already exist. Programs such as these should be greatly expanded, to reach additional classrooms and school systems.

5.1.3 Naturalist programs.

Some of the most receptive audiences to learning about killer whales are people participating in marine wildlife viewing activities. Many whale- watching companies already employ a naturalist on their cruises to provide guests with background information on killer whales and other aspects of the marine environment. Staff and visiting experts at Lime Kiln Point State Park also give summer interpretive talks on the whales. Continuation of naturalist training programs, such as the ones offered by The Whale Museum and the University of Victoria, will ensure that consistent and accurate messages are relayed not just to whale watchers but and other members of the public.

5.2 Expand information and education programs to reduce direct vessel interactions with southern resident killer whales.

Concerns that whale-watching vessels may disturb the southern residents have spawned several successful education programs aimed at reducing interactions between boaters and whales. Viewing guidelines for vessels were first developed in the 1970s and have gradually evolved into the current "Be Whale Wise" campaign, which is a transboundary program created through the cooperative efforts of the whale-watching industry, whale advocacy groups, and government agencies. The campaign has been promoted through on-water stewardship programs, brochures, advertisements, and enforcement agents to a variety of audiences including private boaters, fishers, and the general public.

5.2.1 Expand the on-water educational efforts of the Soundwatch Boater Education Program, Marine Mammal Monitoring Project (M3), and enforcement agencies.

Maintaining on-water stewardship programs to educate vessel operators engaged in whale watching or boating in the vicinity of whales is essential for providing information on viewing guidelines and minimizing vessel impacts on southern resident killer whales (Task 3.1). Such programs should be expanded to allow daily coverage of primary viewing areas during the main viewing season (i.e., May to October) and longer hours of coverage per day. NMFS, WDFW, and DFO enforcement agents have also provided some on-water guidance to vessel operators since 2003 and should expand this activity in cooperation with stewardship programs.

5.2.2 Outreach to private boaters.

On-water stewardship programs (Task 5.2.1) cannot reach every boater. "Be Whale Wise" guidelines and other responsible wildlife viewing messages can be disseminated to private boaters and the general public through the distribution or posting of brochures, billboards, and advertisements in coastal communities, marinas, and fishing literature, at boating shows and boat dealers, and during boating safety training courses.

5.2.3 Encourage land-based viewing of killer whales.

Land-based viewing of killer whales should be advocated as a way for the public to see and enjoy the animals without the impacts of boat viewing. Suitable on-land viewing sites should be identified, promoted, and improved with interpretative facilities and signs.

5.3 Educate the public on positive actions that they can take to improve environmental conditions for southern resident killer whales.

Many private organizations promote environmentally responsible behavior to improve the condition of marine ecosystems within the southern residents' range. Groups focused on the preservation of Puget Sound and the Georgia Basin may be particularly effective with campaigns on contaminant presence and cleanup efforts. Salmon recovery advocates can also assist in reaching the public with salmon concerns and their implications for killer whales. Existing programs range from campaigns encouraging communities and individuals to use environmentally safe lawn products and to safely dispose of hazardous waste to hands-on habitat restoration activities. Additional ongoing and new education efforts will build additional community based support for killer whales, their prey and habitats

5.4 Solicit the public's assistance in finding killer whales.

5.4.1 Solicit reports of killer whale sightings.

Several sighting programs have been established along the west coast of North America to track killer whale and other marine mammal movements. However, much remains unknown about southern resident distribution, particularly during winter months and along the outer coast (Task 4.1). Additional outreach should be directed at recreational boaters, fishers, vessel crews, and a variety of other groups to obtain sighting information that will assist in filling critical data gaps.

5.4.2 Solicit reports of killer whale strandings from the public.

The public should be continually requested to contact regional stranding networks whenever beached killer whales are encountered. Staffed by government biologists with help from volunteers, network phones are monitored daily, including weekends and holidays. Prompt notification is necessary to facilitate rapid rescue of live animals or to investigate dead whales as soon as possible to obtain information about disease, contaminants, and cause of death (Task 6).

6. Respond to killer whales that are stranded, sick, injured, isolated, pose a threat to the public, or exhibit nuisance behaviors.

6.1 Manage atypical individual southern residents.

Marine mammal managers in Washington and British Columbia have twice dealt with young resident calves separated from their pods in the past few years (i.e., L98, "Luna", a southern resident, from 2003-2005; and A73, "Springer", a northern resident, in 2002). It is conceivable that other situations may occur involving solitary southern residents that are out of their normal range, separated from their pod, sick, injured, or interacting negatively with humans. The need for intervention by resource agencies in such situations should be evaluated on a case-by-case basis, based on health of the animal, levels of interactions with people, potential threats, distance separated from other pod members, and other appropriate factors. Transboundary consultations, cooperation, and coordination will be needed, as well as community support.

6.2 Respond to strandings of killer whales.

Killer whale strandings are relatively rare in the northeastern Pacific and normally involve single animals. Strandings generate intense scientific and public interest. Successful responses to strandings must address both interests in a timely and consistent manner. All strandings occurring from central California to northern British Columbia should be responded to because of the possibility that southern resident whales may be involved. Marine mammal stranding investigations in Washington and Oregon are conducted by the Northwest Marine Mammal Stranding Network (NMMSN), which includes resource agencies, local officials, veterinarians, biologists, and volunteer individuals and organizations. Strandings in British Columbia are handled through the Vancouver Aquarium Marine Science Center.

6.2.1 Develop protocols for responding to stranded killer whales.

The NMMSN currently has the capability to respond to stranded killer whales, but advanced planning is crucial to improve rapid and efficient responses to strandings. Response protocols for strandings of live, dead, or entangled whales should be prepared by a working group of resource agencies, members of the NMMSN, cooperating scientists, and education specialists. Protocols should include information on response team personnel, caching and mobilization of equipment, identification of necropsy facilities and testing labs, triage decision making, animal identification, contact lists for geographical areas, and communications policies. Response efforts should be capable of reaching and functioning in remote locations, and should have the capacity to handle multiple animals, given the history of mass strandings in British Columbia during the 1940s. Transboundary coordination is desirable in these efforts (Task 7.1.2).

6.2.2 Respond to live-stranded killer whales.

Live-stranded animals require immediate rescue actions and provide unique opportunities to learn more about the threats facing killer whales. Responses to strandings of live animals should follow the protocols developed under Task 6.2.1 as quickly and safely as possible for responders and the stranded whale. Policies on the collection of samples and attachment of research tags to released animals are needed.

6.2.3 Respond to strandings of dead killer whales.

The carcasses of all stranded killer whales found in the range of the southern residents should be examined and fully necropsied to obtain valuable information on identity, physical condition, disease status, cause of death, contaminant loads, genetic relationships, and diet. Responses to strandings of dead animals should follow the protocols developed under Task 6.2.1. Necropsies should follow the standard protocol recently developed by Raverty and Gaydos (2004).

6.3 Respond to future resource conflicts between the southern residents and humans.

Interactions between fisheries and resident killer whales have been reported in Alaska. In the event that a southern resident-fishery conflict arises, co-managers should take cooperative proactive steps to reduce the conflict. The NMMSN is in place, including members with expertise and equipment, to address immediate needs of individual whales. Management strategies consistent with the MMPA and ESA, and with consideration of public concerns, should be developed and evaluated to resolve such conflicts.

7. Transboundary and interagency coordination and cooperation.

In addition to being designated as a depleted stock under the MMPA, southern resident killer whales are proposed for listing as threatened under the ESA. Washington State's killer whales were added to the state's list of endangered species in 2004, and in Canada, the southern and northern residents are listed as endangered and threatened, respectively, under the Species at Risk Act (SARA). Each designation carries with it an added responsibility for resource agencies to prepare plans or strategies to recover these populations to a healthy condition. The definitions and mandates imposed by each listing or designation are specific to the laws or regulations under which each of the listings or designations are made. Nevertheless, the overarching goals of conservation and population recovery are remarkably similar regardless of jurisdiction. It is recommended that conservation and recovery plans and research efforts be coordinated within and among responsible agencies, federal or state, to ensure that conservation goals are met and that resources for conservation are optimized.

7.1 Cooperative research and monitoring.

To the extent practicable, research into the biology and conservation concerns of the region's killer whale populations should be coordinated among resource agencies, especially in the transboundary area. Interagency cooperation should be encouraged as much as possible through collaborative research planning, complimentary study design, cost or resource sharing, and liberal data dissemination practices. While cooperation and sharing of information is important, professional courtesy and ethical data utilization policies must be maintained to preserve the integrity of the intellectual property of the agencies and individuals participating in the research efforts.

7.1.1 Population monitoring.

To the extent practicable, killer whale photo-identification, censuses, and population demographic studies should be conducted using compatible methodology to allow for consistency and comparison within and among populations, especially in the transboundary area.

7.1.2 Stranding response coordination.

To the extent practicable, killer whale stranding investigations should be coordinated to encourage interagency and international participation and data sharing, especially in the transboundary area (Task 6.2).

7.2 Complimentary conservation and recovery planning.

It should be a goal of resource agencies involved in conservation or recovery planning for southern resident whales to communicate and coordinate during the planning process. Conservation plans, recovery strategies, action plans, and site-specific management measures should be complimentary to the extent practicable given the nuances and mandates of the legislation under which each plan is prepared.

7.2.1 Subject plans to periodic review.

Conservation and recovery plans should be responsive to the current scientific understanding of the factors affecting the decline or conservation of the southern resident population. To remain useful as a tool for improving the current condition, plans should be subject to periodic review and amendment, and incorporate the findings of ongoing research studies as understanding of the factors affecting decline or conservation improve.

7.2.2 Encourage public participation.

The public shall be encouraged to participate in southern resident conservation efforts. Resource agencies should communicate the progress, successes, and failures of implementing recommended management actions contained in conservation and recovery plans.

7.3 Inter-jurisdictional enforcement cooperation and coordination.

To the extent practicable, federal, state, and local law enforcement and legal authorities in the U.S. and Canada should cooperate and encourage the development and implementation of consistent enforcement and prosecution policies, especially in the transboundary area. Where possible, legal impediments to inter-jurisdictional enforcement actions should be streamlined or removed to encourage enforcement efficiency and transparency for the public. A comprehensive legal review of the applicable sections of the laws and regulations in the U.S. (MMPA, ESA, Washington

Administrative Code) and Canada (Fisheries Act, SARA, Provincial Code) should be undertaken to illuminate the similarities and differences between the various laws and regulations. Based on the review, recommendations should be developed for administrative changes to promote consistent interpretation of protective regulations and foster efficient enforcement and prosecution of violations against southern residents and other killer whales. The enforcement and prosecution standards should be transparent and easily understood by the public and based on sound wildlife management principals, recognizing the limitations of science in substantiating clear cause-and-effect relationships between action and reaction in the marine environment.

7.4 Funding for conservation.

As of this writing, funding for research and conservation actions to benefit the conservation of the southern resident population has been secured by the Washington State congressional delegation during each fiscal year 2003, 2004, and 2005. Nevertheless, this conservation plan contains recommended management actions that are inter-departmental, inter-jurisdictional, and international in nature. Long-term funding for management initiatives to implement the recommended actions is needed and should be planned for in agency budgets as appropriations allow. The public should be encouraged to promote conservation plan implementation through their elected representatives at the federal, state, provincial, and local levels.

IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows outlines actions and estimated costs for the conservation program for southern resident killer whales, as set forth in this conservation/ recovery plan. It is a guide for meeting the conservation goals outlined in this plan. This schedule indicates action priorities, action numbers, action descriptions, duration of actions, the parties responsible for actions (either funding or carrying out), and estimated costs. Parties with authority, responsibility, or expressed interest to implement a specific conservation action are identified in the Implementation Schedule. When more than one party has been identified, the proposed lead party is the first party listed. The listing of a party in the Implementation Schedule does not require the identified party to implement the action(s) or to secure funding for implementing the action(s).

Priorities presented in the Implementation Schedule are assigned as follows:

Priority 1	Actions that must be taken to prevent extinction or to prevent the population from declining irreversibly.
Priority 2	Actions that must be taken to prevent a significant decline in the population or its habitat quality, or in some other significant negative impact short of extinction.
Priority 3	All other actions necessary to provide for full conservation of the population.

*Implementation schedules generally project out for five years, however, we intend to capture funding that has already been spent in previous years (i.e., FY03, FY04) in support of southern resident killer whale conservation while the plan is being developed.

** The NWFSC is developing a separate long-term research plan. We will work with the NWFSC to incorporate the priority, responsible party, costs, and timelines from the research plan into the Implementation Schedule.

Key to Acronyms Used in the Implementation Schedule

CTC	Concurrent Technologies Corporation
CWR	Center for Whale Research
DFO	Fisheries and Oceans Canada
EC	Environment Canada
EPA	U.S. Environmental Protection Agency
M3	Marine Mammal Monitoring Project
NGO	Non-Governmental Organizations
NMFS	NOAA Fisheries

NWFSC	NOAA Fisheries, Northwest Fisheries Science Center
NMMSN	Northwest Marine Mammal Stranding Network
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
OLE	NOAA Fisheries, Office of Law Enforcement
SA	Seattle Aquarium
Soundwatch	Soundwatch Boater Education Program
TWM	The Whale Museum
USCG	U.S. Coast Guard
USFWS	U.S. Fish and Wildlife Service
VA	Vancouver Aquarium
WDFW	Washington Department of Fish and Wildlife
WDOE	Washington Department of Ecology
WSP	Washington State Parks and Recreation Commission
WWOANW	Whale Watch Operators Association Northwest

Conservation Plan Implementation Schedule for Southern Resident Killer Whales

Task No.	Task Description	Priority	Responsible Parties	FY04*	FY05	FY06	FY07	FY08
1	**Monitor status and trend of southern resident killer whales**							
1.1	Continue the annual population census	2	CWR					
1.2	Maintain a current photo-identification catalog for southern residents and staff able to photographically identify whales	2	CWR					
1.3	Standardize the results of annual population surveys	3	NMFS, CWR, DFO					
2	**Protect southern resident killer whales from factors causing decline**							
2.1	Rebuild depleted populations of salmon and other prey to ensure an adequate food base for conservation of southern residents							
2.1.1	Support local recovery efforts	2	NMFS, Shared Strategy, state/tribal/local recovery programs, NGO, DFO					
2.1.2	Use NMFS authorities under the ESA and the MSFCMA to protect salmon habitat and regulate salmon harvest	2	NMFS					
2.1.3	Consider effects on southern resident killer whales in managing hatcheries	3	NMFS, WDFW, ODFW, USFWS, tribes, DFO					
2.2	Minimize pollution and chemical contamination in southern resident habitats							
2.2.1	Clean up contaminated sites and sediments							
2.2.1.1	Identify and prioritize specific sites in need of cleanup	2	CTC, NMFS, EC, DFO, EPA, WDOE					
2.2.1.2	Remediate sites in need of cleanup	2	EPA, Superfund, US Navy, others					
2.2.2	Minimize continuing inputs of contaminants into the environment							

Conservation Plan Implementation Schedule for Southern Resident Killer Whales

Task No.	Task Description	Priority	Responsible Parties	FY04*	FY05	FY06	FY07	FY08
2.2.2.1	Minimize the levels of contaminants discharged by industrial and municipal sources of pollution	3	EPA, WDOE, ODEQ, DFO, local/municipal/ provincial					
2.2.2.2	Minimize the levels of contaminants released by non-point sources of pollution	2-3?	EPA, WDOE, ODEQ, DFO, local/municipal/ provincial					
2.2.2.3	Develop environmental monitoring programs for emerging contaminants	3	EPA, WDOE, EC, local/municipal					
2.2.3	Minimize contamination in prey	3	WDFW, ODFW, NMFS, USFWS, tribes, DFO					
2.3	Minimize disturbance of southern resident killer whales from vessels							
2.3.1	Monitor vessel activity around whales							
2.3.1.1	Expand efforts to monitor commercial and recreational whale-watching vessels.	2	Soundwatch, M3, NMFS					
2.3.1.2	Evaluate the relative importance of shipping, ferry, fishing, enforcement, research, and other vessel traffic to disturbance of killer whales.	3	NMFS, CTC					
2.3.2	Continue to evaluate and improve voluntary whale-watching guidelines.	2	NMFS, M3, Soundwatch, DFO, WWOANW					
2.3.3	Evaluate the need to establish regulations regarding vessel activity in the vicinity of whales.	2-3?	NMFS, DFO, USCG					
2.3.4	Evaluate the need to establish areas with restrictions on vessel traffic or closures to vessel traffic.	2-3?	NMFS, DFO, USCG					

Conservation Plan Implementation Schedule for Southern Resident Killer Whales

Task No.	Task Description	Priority	Responsible Parties	FY04*	FY05	FY06	FY07	FY08
3	**Protect the southern resident killer whale population from additional threats with the potential to cause disturbance, injury or mortality or impact habitat**							
3.1	Minimize the risk of large oil spills							
3.1.1	Prevent oil spills	1	USCG, WDOE, EC					
3.1.2	Prepare for and respond to oil spills to minimize their effects on southern resident killer whales	1	NMFS, WDFW, NW Contingency Plan Wildlife Section Working Group					
3.1.3	Develop strategies to deter killer whales from entering spilled oil	2	NMFS, WDFW					
3.2	Reduce the risk of disease pathogens in southern resident habitats							
3.3	Continue to use established MMPA mechanisms to minimize any potential impacts from human activies involving acoustic sources, including Navy tactical sonar, seismic exploration and other sources.	2	NMFS, US Navy					
3.4	Reduce the impacts of invasive species in southern resident habitats							
3.4.1	Prevent the introduction and spread of invasive species	3	WDFW, USFWS, NMFS, USCG, WDOA, ODEQ, DFO					
3.4.2	Eradicate existing populations of invasive species	3	WDFW, USFWS, NMFS, WDOA, ODEQ, DFO					

Task No.	Task Description	Priority	Responsible Parties	FY04*	FY05	FY06	FY07	FY08
4	**Conduct research to facilitate and enhance conservation efforts for southern resident killer whales**		NWFSC**, DFO, researchers, WFDW					
4.1	Determine the distribution and movement patterns of the southern residents							
4.1.1	Determine distribution and movements in outer coastal waters							
4.1.2	Improve knowledge of distribution and movements in the Georgia Basin and Puget Sound							
4.1.3	Determine the effects of prey abundance and availability and other factors on whale distribution and movements							
4.2	Investigate the diet of the southern residents							
4.2.1	Determine the diet of the southern residents							
4.2.2	Determine the importance of specific prey populations to the diet							
4.2.3	Determine the extent of feeding on hatchery fish							
4.3	Analyze the population dynamics of the southern residents							
4.3.1	Determine causes of mortality							
4.3.2	Evaluate survival patterns							
4.3.3	Evaluate reproductive patterns							
4.3.4	Evaluate population structure							
4.3.5	Evaluate changes in social structure							
4.4	Investigate the health and physiology of the southern residents							

Conservation Plan Implementation Schedule for Southern Resident Killer Whales

Task No.	Task Description	Priority	Responsible Parties	FY04*	FY05	FY06	FY07	FY08
4.4.1	Assess the health of population members							
4.4.2	Assess growth rates							
4.4.3	Determine metabolic rates and energy requirements							
4.5	Investigate the behavior of the southern residents							
4.6	Assess threats to the southern residents							
4.6.1	Assess the effects of changes in prey populations							
4.6.1.1	Determine historical changes in prey occurrence and their effects on southern resident population dynamics							
4.6.1.2	Assess changes in prey quality and their effects on southern resident population dynamics							
4.6.1.3	Determine whether the southern residents are limited by critical periods of scarce food resources							
4.6.1.4	Assess threats to prey populations of the southern residents							
4.6.2	Assess the effects of human-generated marine noise and vessel traffic							
4.6.2.1	Determine vessel characteristics that affect the southern residents							
4.6.2.2	Determine the extent that vessels disturb or harm the southern residents							
4.6.2.2.1	Determine the effects of vessels on foraging and other behavior							

Conservation Plan Implementation Schedule for Southern Resident Killer Whales

Task No.	Task Description	Priority	Responsible Parties	FY04*	FY05	FY06	FY07	FY08
4.6.2.3	Determine the extent that other sources of noise disturb or harm the southern residents							
4.6.2.4	Determine the acoustic environment of the southern residents							
4.6.2.5	Determine the hearing capabilities and vocalization behavior of the southern residents near noise sources							
4.6.2.6	Assess the effects of human-generated marine noise on southern resident prey							
4.6.3	Assess the effects of contaminants							
4.6.3.1	Determine contaminant levels in the southern residents and other killer whale communities in the northeastern Pacific							
4.6.3.2	Determine contaminant levels in southern resident prey							
4.6.3.3	Determine the sources of contaminants entering southern resident prey							
4.6.3.4	Determine the effects of elevated contaminant levels on survival, physiology, and reproduction in the southern residents							
4.6.4	Determine risks from other human-related activities							
4.6.5	Evaluate the potential for disease							
4.6.6	Determine the risk of inbreeding							
4.7	Identify important habitats for the southern residents							
4.8	Determine the effects of variable oceanographic conditions on the southern residents and their prey							

Conservation Plan Implementation Schedule for Southern Resident Killer Whales

Task No.	Task Description	Priority	Responsible Parties	FY04*	FY05	FY06	FY07	FY08
4.9	Determine genetic relationships							
4.9.1	Expand the number of genetic samples available for study							
4.9.2	Determine paternity patterns in the southern residents							
4.9.3	Determine genetic relationships among populations							
4.1	Improve research techniques and technology							
5	**Develop public information and education programs**							
5.1	Enhance public awareness of southern resident status and threats							
5.1.1	Exhibits at local museums, aquaria, and parks	3	SA, TWM, WSP, VA, NMFS					
5.1.2	School programs	3	NGO					
5.1.3	Naturalist programs	3	NGO					
5.2	Expand information and education programs to reduce direct vessel interactions with southern resident killer whales							
5.2.1	Expand the on-water educational efforts of Soundwatch, M3, and enforcement agencies	2	NMFS, Soundwatch, M3, WDFW, DFO					
5.2.2	Outreach to private boaters	3	NMFS, Soundwatch, M3, WDFW, DFO					
5.2.3	Encourage land-based viewing of killer whales	3	TWM, Orca Relief, WSP, NGO					
5.3	Educate public on positive actions they can take to improve the current condition for southern resident killer whales	2	NGO, NMFS					

Conservation Plan Implementation Schedule for Southern Resident Killer Whales

Task No.	**Task Description**	**Priority**	**Responsible Parties**	**FY04***	**FY05**	**FY06**	**FY07**	**FY08**
5.4	Solicit the public's assistance in finding killer whales							
5.4.1	Solicit reports of killer whale sightings	3	NMFS, TWM, OrcaNetwork, CWR, BC Sighting Network					
5.4.2	Solicit reports of killer whale strandings from the public	3	NMFS, NMMSN, OrcaNetwork, CWR, BC Sighting Network					
6	**Respond to killer whales that are stranded, sick, injured, isolated, pose a threat to the public, or exhibit nuisance behaviors**							
6.1	Manage atypical individual southern residents	3	NMFS, WDFW, DFO					
6.2	Respond to strandings of killer whales							
6.2.1	Develop protocols for responding to stranded killer whales	3	NMFS, NMMSN, DFO, VA					
6.2.2	Respond to live-stranded killer whales	2-3?	NMFS, NMMSN, DFO, VA					
6.2.3	Respond to strandings of dead killer whales	3	NMFS, NMMSN, DFO, VA					
6.3	Respond to future resource conflicts between the southern residents and humans	3	NMFS, others as identified					
7	**Trans-boundary and interagency coordination and cooperation**							
7.1	Cooperative research and monitoring	3	NMFS, DFO, WDFW, researchers					
7.1.1	Population monitoring	3	NMFS, DFO, WDFW, CWR					
7.1.2	Stranding response coordination	3	NMFS, DFO, WDFW					

Conservation Plan Implementation Schedule for Southern Resident Killer Whales

Task No.	Task Description	Priority	Responsible Parties	FY04*	FY05	FY06	FY07	FY08
7.2	Complimentary conservation and recovery planning							
7.2.1	Plans are subject to periodic review	3	NMFS, DFO, WDFW					
7.2.2	Encourage public participation	3	NMFS, DFO, WDFW					
7.3	Inter-jurisdictional enforcement cooperation and coordination	3	NMFS, DFO, WDFW					
7.4	Funding for conservation	3	NMFS, DFO, WDFW					

LITERATURE CITED

Aguiar dos Santos, R. and M. Haimovici. 2001. Cephalopods in the diet of marine mammals stranded or incidentally caught along southeastern and southern Brazil (21-34ºS). Fisheries Research 52:99-112.

Aguilar, A. and A. Borrell. 1988. Age- and sex-related changes in organochlorine compound levels in fin whales (*Balaenoptera physalus*) from the eastern North Atlantic. Marine Environmental Research 25:195-211.

Aguilar, A. and A. Borrell. 1994a. Reproductive transfer and variation of body load of organochlorine pollutants with age in fin whales (*Balaenoptera physalus*). Archives of Environmental Contamination and Toxicology 27:546-554.

Aguilar, A. and A. Borrell. 1994b. Abnormally high polychlorinated biphenyl levels in striped dolphins (*Stenella coeruleoalba*) affected by the 1990-1992 Mediterranean epizootic. Science of the Total Environment 154:237-247.

Aguilar, A., A. Borrell, and T. Pastor. 1999. Biological factors affecting variability of persistent pollutant levels in cetaceans. Journal of Cetacean Research and Management, Special Issue 1:83-116.

Ainley, D. G. 2002. The Adélie penguin: bellweather of climatic change. Columbia University Press, New York, New York.

AMAP. 1998. AMAP assessment report: arctic pollution issues. Arctic Pollution Issues, Arctic Monitoring and Assessment Programme, Oslo, Norway.

Amos, K. H. and A. Appleby. 1999. Atlantic salmon in Washington State: a fish management perspective. Washington Department of Fish and Wildlife, Olympia, Washington. <http://wdfw.wa.gov/fish/atlantic/toc.htm>.

Andersen, M. and C. C. Kinze. 1999. Annotated checklist and identification key to the whales, dolphins, and porpoises (Order Cetacea) of Thailand and adjacent waters. Natural History Bulletin of the Siam Society 47:27-62.

Anderson, G. R. V. 1982. A re-examination of pregnancy rates and calf ratios in *Orcinus orca*. Report of the International Whaling Commission 32:629-631.

Andrew, R. K., B. M. Howe, and J. A. Mercer. 2002. Ocean ambient sound: comparing the 1960s with the 1990s for a receiver off the California coast. Acoustics Research Letters Online 3, 65-70.

Andrews, R. C. 1914. The California gray whale. Pages 229-287 *in* Monographs of the Pacific Cetacea. Memoirs of the American Museum of Natural History, New Series, Vol. I, Part V. New York, New York.

Angliss, R. P. in prep. Alaska marine mammal stock assessments, 2005. NOAA Technical Memorandum NMFS-AFSC-___, U.S. Department of Commerce, Seattle, Washington.

Angliss, R. P., G. K. Silber, and R. Merrick. 2002. Report of a workshop on developing recovery criteria for large whale species. NOAA Technical Memorandum NMFS-F/OPR-21, U.S. Department of Commerce, Seattle, Washington.

Anonymous. 1954. Killing the killers. Time Magazine 64 (14, October 4):36.

Anonymous. 1956. Killer whales destroyed, VP-7 accomplishes special task. Naval Aviation News 1956 (December):19.

Anonymous. 1981. Chairman's report of the thirty-second annual meeting. Report of the International Whaling Commission 31:17-40.

Ashford, J. R., P. S. Rubilar, and A. R. Martin. 1996. Interactions between cetaceans and longline fishery operations around South Georgia. Marine Mammal Science 12:452-457.

Asper, E. D. and L. H. Cornell. 1977. Live capture statistics for the killer whale (*Orcinus orca*) 1961-1976 in California, Washington and British Columbia. Aquatic Mammals 5:21-26.

Asper, E. D., G. W. Young, and M. T. Walsh. 1988. Observations on the birth and development of a captive-born killer whale. International Zoo Yearbook 27:295-304.

Au, W. W. L. 2002. Echolocation. Pages 358-367 *in* W. F. Perrin, B. Würsig, and J. G. M. Thewissen, editors. Encyclopedia of marine mammals. Academic Press, San Diego, California.

Au, W. W. L., J. K. B. Ford, J. K. Horne, and K. A. Newman Allman. 2004. Echolocation signals of free-ranging killer whales (*Orcinus orca*) and modeling of foraging for chinook salmon (*Oncorhynchus tshawytscha*). Journal of the Acoustical Society of America 115:901-909.

Awbrey, F. T., J. A. Thomas, W. E. Evans, and S. Leatherwood. 1982. Ross Sea killer whale vocalizations: preliminary description and comparison with those of some northern hemisphere killer whales. Report of the International Whaling Commission 32:667-670.

Bain, D. E. 1989. An evaluation of evolutionary processes: studies of natural selection, dispersal, and cultural evolution in killer whales (*Orcinus orca*). Ph.D. thesis, University of California, Santa Cruz, California.

Bain, D. 1990. Examining the validity of inferences drawn from photo-identification data, with special reference to studies of the killer whale (*Orcinus orca*) in British Columbia. Report of the International Whaling Commission, Special Issue 12:93-100.

Bain, D. E. 2002. A model linking energetic effects of whale watching to killer whale (*Orcinus orca*) population dynamics. Friday Harbor Laboratories, University of Washington, Friday Harbor, Washington.

Bain, D. E. and M. E. Dahlheim. 1994. Effects of masking noise on detection thresholds of killer whales. Pages 243-256 *in* T. R. Loughlin, editor. Marine mammals and the *Exxon Valdez*. Academic Press, San Diego, California.

Baird, R. W. 1994. Foraging behaviour and ecology of transient killer whales. Ph.D thesis, Simon Fraser University, Burnaby, British Columbia.

Baird, R. W. 2000. The killer whale: foraging specializations and group hunting. Pages 127-153 *in* J. Mann, R. C. Connor, P. L. Tyack, and H. Whitehead, editors. Cetacean societies: field studies of dolphins and whales. University of Chicago Press, Chicago, Illinois.

Baird, R. W. 2001. Status of killer whales, *Orcinus orca*, in Canada. Canadian Field-Naturalist 115:676-701.

Baird, R. W. 2002. Killer whales of the world: natural history and conservation. Voyageur Press, Stillwater, Minnesota.

Baird, R. W. and L. M. Dill. 1995. Occurrence and behaviour of transient killer whales: seasonal and pod-specific variability, foraging behaviour, and prey handling. Canadian Journal of Zoology 73:1300-1311.

Baird, R. W. and L. M. Dill. 1996. Ecological and social determinants of group size in *transient* killer whales. Behavioral Ecology 7:408-416.

Baird, R. W. and P. J. Stacey. 1988. Variation in saddle patch pigmentation in populations of killer whales (*Orcinus orca*) from British Columbia, Alaska, and Washington State. Canadian Journal of Zoology 66:2582-2585.

Baird, R. W. and H. Whitehead. 2000. Social organization of mammal-eating killer whales: group stability and dispersal patterns. Canadian Journal of Zoology 78:2096-2105.

Baird, R. W., M. B. Hanson, E. A. Ashe, M. R. Heithaus, and G. J. Marshall. 2003. Studies of foraging in “southern resident” killer whales during July 2002: dive depths, bursts in speed, and the use of a “Crittercam” system for examining subsurface behavior. National Marine Fisheries Service, National Marine Mammal Laboratory, Seattle, Washington.

Baird, R. W., M. B. Hanson, and L. M. Dill. In prep. Factors influencing the diving behaviour of fish-eating killer whales: sex differences and diel and inter-annual variation in diving rates. Canadian Journal of Zoology.

Baker C. S., G. M. Lento, F. Cipriano, and S. R. Palumbi. 2000. Predicted decline of protected whales based on molecular genetic monitoring of Japanese and Korean markets. Proceedings of the Royal Society of London, Biological Sciences, Series B 267:1191-1999.

Balcomb, K. C., III. 1982. The occurrence and status of three resident pods of killer whales in Greater Puget Sound, State of Washington. Ocean Research and Education Society, Gloucester, Massachusetts.

Balcomb, K. C. 2002. Observations of a small killer whale in Puget Sound, November 2001? to January 2002. Center for Whale Research, Friday Harbor, Washington. <http://www.whaleresearch.com/thecenter/a73observ.html>.

Balcomb, K. C., III and M. A. Bigg. 1986. Population biology of the three resident killer whale pods in Puget Sound and off southern Vancouver Island. Pages 85-95 *in* B. C. Kirkevold and J. S. Lockard, editors. Behavioral biology of killer whales. Alan R. Liss, New York, New York.

Balcomb, K. C., III, J. R. Boran, and S. L. Heimlich. 1982. Killer whales in greater Puget Sound. Report of the International Whaling Commission 32:681-685.

Balcomb, K. C., III, J. R. Boran, R. W. Osborne, and N. J. Haenel. 1980. Observations of killer whales (*Orcinus orca*) in greater Puget Sound, State of Washington. Report MM1300731-7, U.S. Marine Mammal Commission, Washington, D.C.

Barlow, J. 2003. Preliminary estimates of the abundance of cetaceans along the U.S. west coast: 1991-2001. Administrative Report LJ-03-03, Southwest Fisheries Science Center, National Marine Fisheries Service, La Jolla, California.

Barlow, J., R. W. Baird, J. E. Heyning, K. Wynne, A. M. Manville, L. F. Lowry, D. Hanan, J. Sease, and V. N. Burkanov. 1994. A review of cetacean and pinniped mortality in coastal fisheries along the west coast of the USA and Canada and the east coast of the Russian Federation. Report of the International Whaling Commission, Special Issue 15:405-425.

Barrett-Lennard, L. G. 2000. Population structure and mating patterns of killer whales as revealed by DNA analysis. Ph.D. Thesis, University of British Columbia, Vancouver, British Columbia.

Barrett-Lennard, L. G. and G. M. Ellis. 2001. Population structure and genetic variability in northeastern Pacific killer whales: towards an assessment of population viability. Research Document 2001/065, Fisheries and Oceans Canada, Nanaimo, British Columbia.

Barrett-Lennard, L. G., J. K. B. Ford, and K. A. Heise. 1996. The mixed blessing of echolocation: differences in sonar use by fish-eating and mammal-eating killer whales. Animal Behaviour 51:553-565.

Barrie, L. A., D. Gregor, B. Hargrave, R. Lake, D. Muir, R. Shearer, B. Tracey, and T. Bidleman. 1992. Arctic contaminants: sources, occurrence and pathways. Science of the Total Environment 122:1-74.

Beamish, R. J., D. J. Noakes, G. A. McFarlane, L. Klyashtorin, V. V. Ivanov, and V. Kurashov. 1999. The regime concept and natural trends in the production of Pacific salmon. Canadian Journal of Fisheries and Aquatic Sciences 56:516-526.

Beckmen, K. B., G. M. Ylitalo, R. G. Towell, M. M. Krahn, T. M. O'Hara, and J. E. Blake. 1999. Factors affecting organochlorine contaminant concentrations in milk and blood of northern fur seal (*Callorhinus ursinus*) dams and pups from St. George Island, Alaska. Science of the Total Environment 231:183-200.

Beissinger, S. R. and M. I. Westphal. 1998. On the use of demographic models of population viability in endangered species management. Journal of Wildlife Management 62:821-841.

Béland, P., S. De Guise, C. Girard, A. Lagacé, D. Martineau, R. Michaud, D. C. G. Muir, R. J. Norstrom, E. Pelletier, S. Ray, and L. R. Shugart. 1993. Toxic compounds and health and reproductive effects in St. Lawrence beluga whales. Journal of Great Lakes Research 19:766-775.

Benirschke, K. and L. H. Cornell. 1987. The placenta of the killer whale (*Orcinus orca*). Marine Mammal Science 3:82-86.

Bennett, A. G. 1932. Whaling in the Antarctic. Henry Holt, New York, New York.

Benson, A. J. and A. W. Trites. 2002. Ecological effects of regime shifts in the Bering Sea and eastern North Pacific Ocean. Fish and Fisheries 3:95-113.

Bergman, A., M. Olsson, and S. Reiland. 1992. Skull-bone lesions in the Baltic grey seal (*Halichoerus grypus*). Ambio 21:517-519.

Berzin, A. A. and V. L. Vladimirov. 1983. A new species of killer whale (Cetacea, Delphinidae) from Antarctic waters. Zoologicheskii Zhurnal 62:287-295. (English translation by S. Pearson, National Marine Mammal Laboratory, Seattle, Washington).

Berzin, A. A. and L. P. Vlasova. 1982. Fauna of the cetacean Cyamidae (Amphipoda) of the world ocean. Investigations on Cetacea 13:149-164.

Bigg, M. 1982. An assessment of killer whale (*Orcinus orca*) stocks off Vancouver Island, British Columbia. Report of the International Whaling Commission 32:655-666.

Bigg, M. A. and A. A. Wolman. 1975. Live-capture killer whale (*Orcinus orca*) fishery, British Columbia and Washington, 1962-73. Journal of the Fisheries Research Board of Canada 32:1213-1221.

Bigg, M. A., G. M. Ellis, J. K. B. Ford, and K. C. Balcomb. 1987. Killer whales: a study of their identification, genealogy and natural history in British Columbia and Washington State. Phantom Press and Publishers, Nanaimo, British Columbia.

Bigg, M. A., I. B. MacAskie, and G. Ellis. 1976. Abundance and movements of killer whales off eastern and southern Vancouver Island with comments on management. Arctic Biological Station, Ste. Anne de Bellevue, Quebec.

Bigg, M. A., P. F. Olesiuk, G. M. Ellis, J. K. B. Ford, and K. C. Balcomb III. 1990. Social organization and genealogy of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. Report of the International Whaling Commission, Special Issue 12:383-405.

Bigler, B. S., D. W. Welch, and J. H. Helle. 1996. A review of size trends among North Pacific salmon (*Oncorhynchus* spp.). Canadian Journal of Fisheries and Aquatic Sciences 53:455-465.

Bisson, P. A., T. P. Quinn, G. H. Reeves, and S. V. Gregory. 1992. Best management practices, cumulative effects, and long-term trends in fish abundance in Pacific Northwest river systems. Pages 189-232 *in* R. J. Naiman, editor. Watershed management: balancing sustainability and environmental change. Springer-Verlag, New York, New York.

Bisther, A. 2002. Intergroup interactions among killer whales in Norwegian coastal waters; tolerance vs. aggression at feeding grounds. Aquatic Mammals 28:14-23.

Black, N. A., A. Schulman-Janiger, R. L. Ternullo, and M. Guerrero-Ruiz. 1997. Killer whales of California and western Mexico: a catalog of photo-identified individuals. NOAA Technical Memorandum NMFS-SWFSC-247, U.S. Department of Commerce, San Diego, California.

Black, N., R. Ternullo, A. Schulman-Janiger, A. M. Hammers, and P. Stap. 2001. Occurrence, behavior, and photo-identification of killer whales in Monterey Bay, California. *In* 14th Biennial Conference on the Biology of Marine Mammals, Vancouver, British Columbia. Society for Marine Mammalogy, San Francisco, California.

Blais, J. M., D. W. Schindler, D. C. G. Muir, L. E. Kimpe, D. B. Donald, and B. Rosenberg. 1998. Accumulation of persistent organochlorine compounds in mountains of western Canada. Nature 395:585-588.

Bledsoe, L. J., D. A. Somerton, and C. M. Lynde. 1989. The Puget Sound runs of salmon: an examination of the changes in run size since 1896. Canadian Special Publication of Fisheries and Aquatic Sciences 105:50-61.

Bloch, D. and C. Lockyer. 1988. Killer whales (*Orcinus orca*) in Faroese waters. Rit Fiskideildar 11:55-64.

Bloeser, J. A. 1999. Diminishing returns: the status of West Coast rockfish. Pacific Marine Conservation Council, Astoria, Oregon.

Bonnot, P. 1951. The sea lions, seals and sea otter of the California coast. California Fish and Game 37:371-389.

Boran, J. R. and S. L. Heimlich. 1999. Social learning in cetaceans: hunting, hearing and Hierarchies. Pages 282-307 *in* H. O. Box and K. R. Gibson, editors. Mammalian social learning: comparative and ecological perspectives. Cambridge University Press, Cambridge, United Kingdom.

Borrell, A., D. Bloch, and G. Desportes. 1995. Age trends and reproductive transfer of organochlorine compounds in long-finned pilot whales from the Faroe Islands. Environmental Pollution 88:283-292.

Bowers, C. A. and R. S. Henderson. 1972. Project deep ops: deep object recovery with pilot and killer whales. Naval Undersea Warfare Center, Newport, Rhode Island.

Bowles, A. E., W. G. Young, and E. D. Asper. 1988. Ontogeny of stereotyped calling of a killer whale calf, *Orcinus orca*, during her first year. Rit Fiskideildar 11:251-275.

Braham, H. W. and M. E. Dahlheim. 1982. Killer whales in Alaska documented in the Platforms of Opportunity Program. Report of the International Whaling Commission 32:643-646.

Branch, T. A. and D. S. Butterworth. 2001. Estimates of abundance south of 60°S for cetacean species sighted frequently on the 1978/79 to 1997/98 IWC/IDCR-SOWER sighting surveys. Journal of Cetacean Research and Management 3:251-270.

Brault, S. and H. Caswell. 1993. Pod-specific demography of killer whales (*Orcinus orca*). Ecology 74:1444-1454.

Brouwer, A., P. H. J. Reijnders, and J. H. Koeman. 1989. Polychlorinated biphenyl (PCB)-contaminated fish induces vitamin A and thyroid hormone deficiency in the common seal (*Phoca vitulina*). Aquatic Toxicology 15:99-106.

Brown, L. R., P. B. Moyle, and R. M. Yoshiyama. 1994. Historical decline and current status in coho salmon in California. North American Journal of Fisheries Management 14:237-261.

Brownell, R. L., Jr. and A. V. Yablokov. 2002. Illegal and pirate whaling. Pages 608-612 *in* W. F. Perrin, B. Würsig, and J. G. M. Thewissen, editors. Encyclopedia of marine mammals. Academic Press, San Diego, California.

Budker, P. 1958. Whales and whaling. George G. Harrap and Company, London, United Kingdom.

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-27, U.S. Department of Commerce, Seattle, Washington.

Butterworth, D. S., D. L. Borchers, S. Chalis, J. G. de Decker, and F. Kasamatsu. 1994. Estimates of abundance for Southern Hemisphere blue, fin, sei, humpback, sperm, killer and pilot whales from the 1978/79 to 1990/91 IWC/IDCR sighting survey cruises, with extrapolations to the area south of 30°S for the first five species based on Japanese scouting vessel data. Report number SC/46/SH24, International Whaling Commission, Cambridge, United Kingdom.

Calambokidis, J. and J. Barlow. 1991. Chlorinated hydrocarbon concentrations and their use for describing population discreteness in harbor porpoises from Washington, Oregon, and California. Pages 101-110 *in* J. E. Reynolds III and D. K. Odell, editors. Marine mammals strandings in the United States: proceedings of the second marine mammal stranding workshop, 3-5 December 1987, Miami, Florida. NOAA Technical Report NMFS 98, National Oceanic and Atmospheric Administration, Rockville, Maryland.

Calambokidis, J., S. Jeffries, P. S. Ross, and M. Ikonomu. 1999. Temporal trends in Puget Sound harbor seals. Final Report for the U.S. Environmental Protection Agency and Puget Sound Water Quality Action Team, Cascadia Research, Olympia, Washington.

Calambokidis, J., J. Peard, G. H. Steiger, J. C. Cubbage, and R. L. DeLong. 1984. Chemical contaminants in marine mammals from Washington State. NOAA Technical Memorandum NOS OMS6, National Technical Information Service, Springfield, Virginia.

Calambokidis, J., G. H. Steiger, D. K. Ellifrit, B. L. Troutman, and C. E. Bowlby. 2004. Distribution and abundance of humpback whales (*Megaptera novaeangliae*) and other marine mammals off the northern Washington coast. Fishery Bulletin 102:563-580.

Calambokidis, J., G. H. Steiger, L. J. Lowenstine, and D. S. Becker. 1991. Chemical contamination of harbor seal pups in Puget Sound. Report EPA 910/9-91-032, U.S. Environmental Protection Agency, Seattle, Washington.

Caldwell, D. K. and D. H. Brown. 1964. Tooth wear as a correlate of described feeding behavior by the killer whale, with notes on a captive specimen. Bulletin of the Southern California Academy of Science 63:128-140.

Caldwell, D. K. and M. C. Caldwell. 1969. The addition of the leatherback sea turtle to the known prey of the killer whale, *Orcinus orca*. Journal of Mammalogy 50:636.

Caldwell, M. C. and D. K. Caldwell. 1966. Epimeletic (care-giving) behaviour in Cetacea. Pages 755-789 *in* K. S. Norris, editor. Whales, porpoises and dolphins. University of California Press, Berkeley, California.

California Department of Fish and Game. 1965. California fish and wildlife plan. Volume III, supporting data. Part B, inventory (salmon-steelhead and marine resources). California Department of Fish and Game, Sacramento, California.

Cameron, W. M. 1941. Killer whales stranded near Masset. Progress Report, Biological Station Nanaimo, British Columbia and Pacific Fisheries Experiment Station, Prince Rupert, British Columbia 49:16-17.

Candy, J. R. and T. P. Quinn. 1999. Behavior of adult chinook salmon (*Oncorhynchus tshawytscha*) in British Columbia coastal waters determined from ultrasonic telemetry. Canadian Journal of Zoology 77:1161-1169.

Carl, G. C. 1946. A school of killer whales stranded at Estevan Point, Vancouver Island. Report of the Provincial Museum of Natural History and Anthropology (Victoria, British Columbia) 1945:B21-B28.

Carl, G. C. 1959. Albinistic killer whales in British Columbia. Report of the Provincial Museum of Natural History and Anthropology (Victoria, British Columbia) 1959:29-36.

Carretta, J. V., J. Barlow, K. A. Forney, M. M. Muto, and J. Baker. 2001. U.S. Pacific marine mammal stock assessments: 2001. NOAA Technical Memorandum NMFS-SWFSC-317, U.S. Department of Commerce, San Diego, California.

Carretta, J. V., K. A. Forney, M. M. Muto, J. Barlow, J. Baker, and M. Lowry. 2004. U.S. Pacific marine mammal stock assessments: 2003. NOAA Technical Memorandum NMFS-SWFSC-358, U.S. Department of Commerce, San Diego, California.

Center for Biological Diversity. 2001. Petition to list the southern resident killer whale (*Orcinus orca*) as an endangered species under the Endangered Species Act. Center for Biological Diversity, Berkeley, California.

Christensen, I. 1984. Growth and reproduction of killer whales, *Orcinus orca*, in Norwegian coastal waters. Report of the International Whaling Commission, Special Issue 6:253-258.

Christensen, I. 1988. Distribution, movements and abundance of killer whales (*Orcinus orca*) in Norwegian coastal waters, 1982-1987, based on questionnaire surveys. Rit Fiskideildar 11:79-88.

Clark, R. B. 1997. Marine pollution. 4th edition. Clarendon Press, Oxford, United Kingdom.

Clark, S. T. and D. K. Odell. 1999. Allometric relationships and sexual dimorphism in captive killer whales (*Orcinus orca*). Journal of Mammalogy 80:777-785.

Clark, S. T., D. K. Odell, and C. T. Lacinak. 2000. Aspects of growth in captive killer whales (*Orcinus orca*). Marine Mammal Science 16:110-123.

Cockcroft, V. G., A. C. de Kock, D. A. Lord, and G. J. B. Ross. 1989. Organochlorines in bottlenose dolphins, *Tursiops truncatus*, from the east coast of South Africa. South African Journal of Marine Science 8:207-217.

Cohen, A. N. 2004. An exotic species detection program for Puget Sound. Publication #OTH04-02, Puget Sound Action Team, Olympia, Washington.

Colborn, T. and M. J. Smolen. 2003. Cetaceans and contaminants. Pages 291-332 *in* J. G. Vos, G. D. Bossart, M. Fournier, and T. J. O'Shea, editors. Toxicology of marine mammals. Taylor & Francis, London.

Condy, P. R., R. J. van Aarde, and M. N. Bester. 1978. The seasonal occurrence of killer whales *Orcinus orca*, at Marion Island. Journal of Zoology (London) 184:449-464.

Corkeron, P. J. and R. C. Conner. 1999. Why do baleen whales migrate? Marine Mammal Science 15:1228-1245.

Corkeron, P. J., R. J. Morris, and M. M. Bryden. 1987. Interactions between bottlenose dolphins and sharks in Moreton Bay, Queensland. Aquatic Mammals 13:109-113.

Courchamp, F. T. Clutton-Brock, and B. Grenfell. 1999. Inverse density dependence and the Allee effect. Trends in Ecology and Evolution 14:405-410.

Crowell, S. A. 1983. Whaling off the Washington coast. Washington Print, Hoquiam, Washington.

Cullon, D. L., S. J. Jeffries, M. J. Whiticar, and P. S. Ross. 2004. Assessing the dietary exposure of harbour seals *(Phoca vitulina)* to persistent organic pollutants (POPs) in the Strait of Georgia (British Columbia, Canada) and Puget Sound (Washington State, USA). *in* T. W. Droscher and D. A. Fraser, editors. Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. <http://www.psat.wa.gov/Publications/03_proceedings/start.htm>.

Dahlheim, M. E. 1980. Killer whales observed bowriding. Murrelet 61:78.

Dahlheim, M. E. 1981. A review of the biology and exploitation of the killer whale, *Orcinus orca*, with comments on recent sightings from Antarctica. Report of the International Whaling Commission 31:541-546.

Dahlheim, M. E. 1988. Killer whale (*Orcinus orca*) depredation on longline catches of sablefish (*Anoplopoma fimbria*) in Alaskan waters. NWAFC Processed Report 88-14, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle, Washington.

Dahlheim, M. E. 1994. Abundance and distribution of killer whales, *Orcinus orca*, in Alaska. Annual Report to the MMPA Assessment Program, Office of Protected Resources, National Marine Fisheries Service, Silver Springs, Maryland.

Dahlheim, M. E. 1997. A photographic catalog of killer whales, *Orcinus orca*, from the central Gulf of Alaska to the southeastern Bering Sea. NOAA Technical Report NMFS 131, U.S. Department of Commerce, Seattle, Washington.

Dahlheim, M. E. and F. Awbrey. 1982. A classification and comparison of vocalizations of captive killer whales. Journal of the Acoustical Society of America 72:661-670.

Dahlheim, M. E. and J. E. Heyning. 1999. Killer whale *Orcinus orca* (Linnaeus, 1758). Pages 281-322 *in* S. Ridgway and R. Harrison, editors. Handbook of marine mammals. Academic Press, San Diego, California.

Dahlheim, M. E. and C. O. Matkin. 1994. Assessment of injuries to Prince William Sound killer whales. Pages 163-171 *in* T. R. Loughlin, editor. Marine mammals and the *Exxon Valdez*. Academic Press, San Diego, California.

Dahlheim, M. E., D. K. Ellifrit, and J. D. Swenson. 1997. Killer whales of southeast Alaska: a catalogue of photo-identified individuals. National Marine Mammal Laboratory, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington.

Dahlheim, M. E., S. Leatherwood, and W. F. Perrin. 1982. Distribution of killer whales in the warm temperate and tropical eastern Pacific. Report of the International Whaling Commission 32:647-653.

Dailey, M. D. and R. L. Brownell, Jr. 1972. A checklist of marine mammal parasites. Pages 528-589 *in* S. H. Ridgway, editor. Mammals of the sea: biology and medicine. Charles C. Thomas, Springfield, Illinois.

Darnerud, P. O. 2003. Toxic effects of brominated flame retardants in man and in wildlife. Environment International 29:841-853.

Deecke, V. B., J. K. B. Ford, and P. Spong. 2000. Dialect change in resident killer whales: implication for vocal learning and cultural transmission. Animal Behaviour 60:629-638.

Deecke, V. B., P. J. B. Slater, and J. K. B. Ford. 2002. Selective habituation shapes acoustic predator recognition in harbour seals. Nature 420:171-173.

De Guise, S., K. B. Beckmen, and S. D. Holladay. 2003. Contaminants and marine mammal immunotoxicology and pathology. Pages 38-54 *in* J. G. Vos, G. D. Bossart, M. Fournier, and T. J. O'Shea, editors. Toxicology of marine mammals. Taylor & Francis, London.

DeLong, R. L., W. G. Gilmartin, and J. G. Simpson. 1973. Premature births in California sea lions: association with high organochlorine pollutant residue levels. Science 181:1168-1170.

DeMaster, D. P. and J. K. Drevenak. 1988. Survivorship patterns in three species of captive cetaceans. Marine Mammal Science 4:297-311.

de Swart et al. 1989. Need citation.

de Swart, R. L., R. M. G. Kluten, C. J. Huizing, E. J. Vedder, P. J. H. Reijnders, I. K. G. Visser, F. G. C. M. Uytel-Haag, and A. D. M. E. Osterhaus. 1993. Mitogen and antigen induced B cell and T cell responses of peripheral blood mononuclear cells from the harbour seal (*Phoca vitulina*). Veterinary Immunology and Immunopathology 37:217-230.

de Swart, R. L., P. S. Ross, L. J. Vedder, H. H. Timmerman, S. H. Heisterkamp, H. Van Loveren, J. G. Vos, P. J. H. Reijnders, and A. D. M. E. Osterhaus. 1994. Impairment of immune function in harbor seals (*Phoca vitulina*) feeding on fish from polluted waters. Ambio 23:155-159.

de Swart, R. L., P. S. Ross, J. G. Vos, and A. D. M. E. Osterhaus. 1996. Impaired immunity in harbor seals (*Phoca vitulina*) exposed to bioaccumulated environmental contaminants: review of a long-term study. Environmental Health Perspectives 104 (supplement 4):823-828.

de Wit, C. A. 2002. An overview of brominated flame retardants in the environment. Chemosphere 46:583-624.

DFO (Department of Fisheries and Oceans). 1999. Fraser River chinook salmon. DFO Science Stock Status Report D6-11, Department of Fisheries and Oceans, Nanaimo, British Columbia.

DFO (Department of Fisheries and Oceans). 2001. 2000 Pacific region state of the ocean. DFO Science Ocean Status Report 2001/01, Department of Fisheries and Oceans, Nanaimo, British Columbia.

DFO (Fisheries and Oceans Canada). 2002a. Strait of Georgia herring. Stock Status Report B6-05, Fisheries and Oceans Canada, Nanaimo, British Columbia.

DFO (Fisheries and Oceans Canada). 2002b. Lingcod (*Ophiodon elongatus*). Stock Status Report A6-18, Fisheries and Oceans Canada, Nanaimo, British Columbia.

DFO (Fisheries and Oceans Canada). 2003. Atlantic salmon watch program (ASWP). Fisheries and Oceans Canada, Nanaimo, British Columbia. <http://www.pac.dfo-mpo.gc.ca/sci/aqua/ASWP_e.htm>.

Diercks, K. J., R. T. Trochta, and W. E. Evans. 1973. Delphinid sonar: measurement and analysis. Journal of the Acoustical Society of America 54:200-204.

Doroff, A. M., J. A. Estes, M. T. Tinker, D. M. Burn, and T. J. Evans. 2003. Sea otter population declines in the Aleutian archipelago. Journal of Mammalogy 84:44-64.

Duffield, D. A. and K. W. Miller. 1988. Demographic features of killer whales in oceanaria in the United States and Canada, 1965-1987. Rit Fiskideildar 11:297-306.

Duffield, D. A., D. K. Odell, J. F. McBain, and B. Andrews. 1995. Killer whale (*Orcinus orca*) reproduction at Sea World. Zoo Biology 14:417-430.

Duffus, D. A. and P. Deardon. 1993. Recreational use, valuation, and management, of killer whales (*Orcinus orca*) on Canada's Pacific coast. Environmental Conservation 20:149-156.

Eder, T. 2001. Whales and other marine mammals of Washington and Oregon. Lone Pine Publishing, Renton, Washington.

Eldredge, L. G. 1991. Annotated checklist of the marine mammals of Micronesia. Micronesica 24:217-230.

Erbe, C. 2002. Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. Marine Mammal Science 18:394-418.

Erickson, A. W. 1978. Population studies of killer whales (*Orcinus orca*) in the Pacific Northwest: a radio-marking and tracking study of killer whales. U.S. Marine Mammal Commission, Washington, D.C.

Eschricht, D. F. 1866. On the species of the genus *Orca* inhabiting the northern seas. Pages 151-188 *in* W. H. Flower, editor. Recent memoirs on the Cetacea. Ray Society, London, United Kingdom.

Estes, J. A., M. T. Tinker, T. M. Williams, and D. F. Doak. 1998. Killer whale predation on sea otters linking oceanic and nearshore ecosystems. Science 282:473-476.

Evans, P. G. H. 1988. Killer whales (*Orcinus orca*) in British and Irish waters. Rit Fiskideildar 11:42-54.

Evans, W. E., A. V. Yablokov, and A. E. Bowles. 1982. Geographic variation in the color pattern of killer whales. Report of the International Whaling Commission 32:687-694.

EVS Environmental Consultants. 2003. Status, trends and effects of toxic contaminants in the Puget Sound environment. Puget Sound Action Team, Olympia, Washington.

Ewald, G., P. Larsson, H. Linge, L. Okla, and N. Szarzi. 1998. Biotransport of organic pollutants to an inland Alaska lake by migrating sockeye salmon (*Oncorhynchus nerka*). Arctic 51:40-47.

Felleman, F. L., J. R. Heimlich-Boran, and R. W. Osborne. 1991. The feeding ecology of killer whales (*Orcinus orca*) in the Pacific Northwest. Pages 113-147 *in* K. Pryor and K. S. Norris, editors. Dolphin societies: discoveries and puzzles. University of California Press, Berkeley, California.

Fertl, D. and A. M. Landry, Jr. 1999. Sharksucker (*Echeneis naucrates*) on a bottlenose dolphin (*Tursiops truncatus*) and a review of other cetacean-remora associations. Marine Mammal Science 15:859-863.

Fertl, D., A. Acevedo-Gutiérrez, and F. L. Darby. 1996. A report of killer whales (*Orcinus orca*) feeding on a carcharhinid shark in Costa Rica. Marine Mammal Science 12:606-611.

Fiscus, C. H. and K. Niggol. 1965. Observations of cetaceans off California, Oregon and Washington. Special Scientific Report, Fisheries, No. 498, U.S. Fish and Wildlife Service, Washington, D.C.

Fisheries and Oceans Canada. 2002. Protecting Canada's marine mammals: proposed regulatory amendments. Marine Mammal Bulletin 2002 (December):1-5.

Flagg, T. A., F. W. Waknitz, D. J. Maynard, G. B. Milner, and C. V. W. Mahnken. 1995. The effect of hatcheries on native coho salmon populations in the lower Columbia River. American Fisheries Society Symposium 15:366-375.

Foote, A. D., R. W. Osborne, and A. R. Hoelzel. 2004. Whale-call response to masking boat noise. Nature 428:910.

Ford, J. K. B. 1989. Acoustic behavior of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia. Canadian Journal of Zoology 67:727-745.

Ford, J. K. B. 1991. Vocal traditions among resident killer whales (*Orcinus orca*) in coastal waters of British Columbia. Canadian Journal of Zoology 69:1451-1483.

Ford, J. K. B. 2002. Killer whale *Orcinus orca*. Pages 669-676 *in* W. F. Perrin, B. Würsig, and J. G. M. Thewissen, editors. Encyclopedia of marine mammals. Academic Press, San Diego, California.

Ford, J. K. B. and G. M. Ellis. 1999. Transients: mammal-hunting killer whales of British Columbia, Washington, and southeastern Alaska. UBC Press, Vancouver, British Columbia.

Ford, J. K. B. and G. M. Ellis. 2002. Reassessing the social organization of resident killer whales in British Columbia. *In* Conference abstracts: Fourth international orca symposium and workshop, 23-28 September 2002. Centre d'Etudes Biologiques de Chizé, Chizé, France.

Ford, J. K. B., G. M. Ellis, L. G. Barrett-Lennard, A. B. Morton, R. S. Palm, and K. C. Balcomb III. 1998. Dietary specialization in two sympatric populations of killer whales (*Orcinus orca*) in coastal British Columbia and adjacent waters. Canadian Journal of Zoology 76:1456-1471.

Ford, J. K. B., G. M. Ellis, and K. C. Balcomb. 1994. Killer whales: the natural history and genealogy of *Orcinus orca* in British Columbia and Washington State. UBC Press, Vancouver, British Columbia.

Ford, J. K. B., G. M. Ellis, and K. C. Balcomb. 2000. Killer whales: the natural history and genealogy of *Orcinus orca* in British Columbia and Washington State. 2nd ed. UBC Press, Vancouver, British Columbia.

Ford, J. K. B., G. M. Ellis, and L. M. Nichol. 1992. Killer whales of the Queen Charlotte Islands: a preliminary study of the abundance, distribution and population identity of *Orcinus orca* in the waters of Haida Gwaii. Prepared for South Moresby/Gwaii Haanas National Park Reserve, Canadian Parks Service. Vancouver Aquarium, Vancouver, British Columbia.

Fordyce, R.E. and L. G. Barnes. 1994. The evolutionary history of whales and dolphins. Annual Review of Earth and Planetary Sciences 22:419-455.

Forney, K. A. and P. Wade. In press. Worldwide distribution and abundance of killer whales. *In* J. A. Estes, R. L. Brownell, Jr., D. P. DeMaster, D. F. Doak, and T. M. Williams, editors. Whales, whaling and ocean ecosystems. University of California Press, Berkeley, California.

Fowler, C. W. 1984. Density dependence in cetacean populations. Report of the International Whaling Commission, Special Issue 6:373-379.

Francis, R. C., S. R. Hare, A. B. Hollowed, and W. S. Wooster. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. Fisheries Oceanography 7:1-21.

Frankham, R., J. D. Ballou, and D. A. Briscoe. 2002. Introduction to conservation genetics. Cambridge University Press, Cambridge, United Kingdom.

Fraser, F. C. and P. E. Purves. 1960. Hearing in cetaceans. Bulletin of the British Museum (Natural History), Zoology 7:1-140.

Gallaugher, P. and C. Orr. 2000. Aquaculture and the protection of wild salmon. Continuing Studies in Science, Simon Fraser University, Burnaby, British Columbia.

Gardner, J. and D. L. Peterson. 2003. Making sense of the salmon aquaculture debate: analysis of issues related to netcage salmon farming and wild salmon in British Columbia. Pacific Fisheries Resource Conservation Council, Vancouver, British Columbia.

Gardner, J., D. L. Peterson, A. Wood, and V. Maloney. 2004. Making sense of the debate about hatchery impacts: interactions between enhanced and wild salmon on Canada's Pacific coast. Pacific Fisheries Resource Conservation Council, Vancouver, British Columbia.

Garrett, C. 2004. Priority substances of interest in the Georgia Basin: profiles and background information on current toxics issues. GBAP Publication Number EC/GB/04/79, Canadian Toxics Work Group, Puget Sound/Georgia Basin International Task Force, Victoria, British Columbia, and Olympia, Washington.

Gaydos, J. K., K. C. Balcomb, III, R. W. Osborne, and L. Dierauf. 2004. Evaluating potential infectious disease threats for southern resident killer whales, *Orcinus orca*: a model for endangered species. Biological Conservation 117:253-262.

Geraci, J. R. 1990. Physiological and toxic effects on cetaceans. Pages 167-197 *in* J. R. Geraci and D. J. St. Aubin, editors. Sea mammals and oil: confronting the risks. Academic Press, New York.

Geraci, J. R. and D. J. St. Aubin, editors. 1990. Sea mammals and oil: confronting the risks. Academic Press, New York.

Gibson, D. I. and R. A. Bray. 1997. *Oschmarinella albamarina* (Treshchev, 1968) n. comb., a liver fluke from the killer whale *Orcinus orca* (L.) off the British coast. Systematic Parasitology 36:39-45.

Gibson, D. I., E. A. Harris, R. A. Bray, P. D. Jepson, T. Kuiken, J. R. Baker, and V. R. Simpson. 1998. A survey of the helminth parasites of cetaceans stranded on the coast of England and Wales during the period 1990-1994. Journal of Zoology (London) 244:563-574.

Gilmartin, W. G., R. L. DeLong, A. W. Smith, J. C. Sweeney, B. W. De Lappe, R. W. Risebrough, L. A. Griner, M. D. Dailey, and D. B. Peakall. 1976. Premature parturition in the California sea lion. Journal of Wildlife Diseases 12:104-115.

Gilmore, R. 1976. Killer whales in the San Diego area, Del Mar to the Coronado Islands. American Cetacean Society Newsletter, San Diego, California.

Goley, P. D. and J. M. Straley. 1994. Attack on gray whales (*Eschrichtius robustus*) in Monterey Bay, California, by killer whales (*Orcinus orca*) previously identified in Glacier Bay, Alaska. Canadian Journal of Zoology 72:1528-1530.

Gordon, J. and A. Moscrop. 1996. Underwater noise pollution and its significance for whales and dolphins. Pages 281-319 *in* M. P. Simmonds and J. D. Hutchinson, editors. The conservation of whales and dolphins: science and practice. John Wiley & Sons, Chichester, United Kingdom.

Grant, S. C. H. and P. S. Ross. 2002. Southern resident killer whales at risk: toxic chemicals in the British Columbia and Washington environment. Canadian Technical Report of Fisheries and Aquatic Sciences 2412:1-111.

Gray, C. and T. Tuominen. 2001. The Fraser River is getting cleaner: will it continue to improve? *In* T. Droscher, editor. Proceedings of the 2001 Puget Sound Research Conference. Puget Sound Action Team. Olympia, Washington.

Green, G. A., J. J. Brueggeman, R. A. Grotefendt, C. E. Bowlby, M. L. Bonnell, and K. C. Balcomb, III. 1992. Cetacean distribution and abundance off Oregon and Washington. Pages 1-1 to 1-100 *in* J. J. Brueggeman, editor. Oregon and Washington marine mammal and seabird surveys. Pacific OCS Region, Minerals Management Service, U.S. Department of the Interior, Los Angeles, California.

Green, G. A., R. A. Grotefendt, M. A. Smultea, C. E. Bowlby, and R. A. Rowlett. 1993. Delphinid aerial surveys in Oregon and Washington offshore waters. National Marine Mammal Laboratory, National Marine Fisheries Service, Seattle, Washington.

Greenwood, A. G. and D. C. Taylor. 1985. Captive killer whales in Europe. Aquatic Mammals 1:10-12.

Gregory, M. and D. G. Cyr. 2003. Effects of environmental contaminants on the endocrine system of marine mammals. Pages 67-81 *in* J. G. Vos, G. D. Bossart, M. Fournier, and T. J. O'Shea, editors. Toxicology of marine mammals. Taylor & Francis, London.

Gregory, S. V. and P. A. Bisson. 1997. Degradation and loss of anadromous salmonid habitat in the Pacific Northwest. Pages 277-314 *in* D. J. Stouder, P. A. Bisson, and R. J. Naiman, editors. Pacific salmon & their ecosystems: status and future options. Chapman & Hall, New York, New York.

Gregr, E. J., L. Nichol, J. K. B. Ford, G. Ellis, A. W. Trites. 2000. Migration and population structure of northeastern Pacific whales off coastal British Columbia: an analysis of commercial whaling records from 1908-1967. Marine Mammal Science 16:699-727.

Groot, C. and L. Margolis, editors. 1991. Pacific salmon life histories. UBC Press, Vancouver, British Columbia.

Groot, C. and T. P. Quinn. 1987. Homing migration of sockeye salmon, *Oncorhynchus nerka*, to the Fraser River. Fishery Bulletin 85:455-469.

Guenther, T. J., R. W. Baird, R. L. Bates, P. M. Willis, R. L. Hahn, and S. G. Wischniowski. 1995. Strandings and fishing gear entanglements of cetaceans on the west coast of Canada in 1994. Report number SC/47/O6, International Whaling Commission, Cambridge, United Kingdom.

Guerrero-Ruiz, M. 1997. Conocimiento actual de la orca (*Orcinus orca* Linnaeus, 1758) en el Golfo de California. Tesis de Licenciatura, Universidad Autónoma de Baja California Sur, La Paz, Baja California Sur, Mexico.

Guerrero-Ruiz, M. and J. Urbán R. 2000. First report of remoras on two killer whales (*Orcinus orca*) in the Gulf of California, Mexico. Aquatic Mammals 26:148-150.

Guerrero-Ruiz, M., D. Gendron, and J. Urbán R. 1998. Distribution, movements and communities of killer whales (*Orcinus orca*) in the Gulf of California, Mexico. Report of the International Whaling Commission 48:537-543.

Guinet, C. 1991. Intentional stranding apprenticeship and social play in killer whales (*Orcinus orca*). Canadian Journal of Zoology 69:2712-2716.

Guinet, C. and J. Bouvier. 1995. Development of intentional stranding hunting techniques in killer whale (*Orcinus orca*) calves at Crozet Archipelago. Canadian Journal of Zoology 73:27-33.

Guinet, C., L. G. Barrett-Lennard, and B. Loyer. 2000. Co-ordinated attack behavior and prey sharing by killer whales at Crozet Archipelago: strategies for feeding on negatively-buoyant prey. Marine Mammal Science 16:829-834.

Guldberg, G. and F. Nansen. 1894. On the development and structure of the whale. Part I. On the development of the dolphin. Bergen Museum, Bergen, Norway.

Gustafson, R. C., T. C. Wainwright, G. A. Winans, F. W. Waknitz, L. T. Parker, and R. S. Waples. 1997. Status review of sockeye salmon from Washington and Oregon. NOAA Technical Memorandum NMFS-NWFSC-33, U.S. Department of Commerce, Seattle, Washington.

Haenel, N.J. 1986. General notes on the behavioral ontogeny of Puget Sound killer whales and the occurrence of allomaternal behavior. Pages 285-300 *in* B. C. Kirkevold and J. S. Lockard, editors. Behavioral biology of killer whales. Alan R. Liss, New York, New York.

Haley, D. 1970. Views on the killer whale dispute. Pacific Search 5(1):1-3.

Haley, D. 1973. Albino killer whale. Sea Frontiers 19:66-71.

Hall, A. J., O. I. Kalantzi, and G. O. Thomas. 2003. Polybrominated diphenyl ethers (PBDEs) in grey seals during their first year of life – are they thyroid hormone endocrine disrupters? Environmental Pollution 126:29-37.

Hall, A. J., R. J. Law, J. Harwood, H. M. Ross, S. Kennedy, C. R. Allchin, L. A. Campbell, and P. P. Pomeroy. 1992. Organochlorine levels in common seals (*Phoca vitulina*) which were victims and survivors of the 1988 phocine distemper epizootic. Science of the Total Environment 115:145-162.

Hammond, P. S. 1984. Abundance of killer whales in Antarctic Areas II, III, IV and V. Report of the International Whaling Commission 34:543-548.

Hammond, P. S., S. A. Mizroch, and G. P. Donovan, editors. 1990. Individual recognition of cetaceans: use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission, Special Issue 12:1-440.

Hanson, E. and M. Sytsma. 2001. Oregon aquatic nuisance species management plan. Center for Lakes and Reservoirs, Portland State University, Portland, Oregon.

Hard, J. J., R. G. Kope, W. S. Grant, F. W. Waknitz, L. T. Parker, and R. S. Waples. 1996. Status review of pink salmon from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-25, U.S. Department of Commerce, Seattle, Washington.

Hare, S. R., N. J. Mantua, and R. C. Francis. 1999. Inverse production regimes: Alaskan and west coast salmon. Fisheries 24(1):6-14.

Hart, T. J. 1935. On the diatoms of the skin film of whales, and their possible bearing on problems of whale movements. Discovery Report 10:247-282.

Hartwell, S. I. 2004. Distribution of DDT in sediments off the central California coast. Marine Pollution Bulletin 49:299-305.

Hatfield, B. B., M. T. Tinker, K. Nolan, and J. Pierce. 1998. Attacks on sea otters by killer whales. Marine Mammal Science 14:888-894.

Hayteas, D. L. and D. A. Duffield. 2000. High levels of PCB and *p,p'*-DDE found in the blubber of killer whales (*Orcinus orca*). Marine Pollution Bulletin 40:558-561.

Heide-Jørgensen, M.-P. 1988. Occurrence and hunting of killer whales in Greenland. Rit Fiskideildar 11:115-135.

Heimlich-Boran, J. R. 1986a. Fishery correlations with the occurrence of killer whales in Greater Puget Sound. Pages 113-131 *in* B. C. Kirkevold and J. S. Lockard, editors. Behavioral biology of killer whales. Alan R. Liss, New York, New York.

Heimlich-Boran, J. R. 1988. Behavioral ecology of killer whales (*Orcinus orca)* in the Pacific Northwest. Canadian Journal of Zoology 66:565-578.

Heimlich-Boran, S. L. 1986b. Cohesive relationships among Puget Sound killer whales. Pages 251-284 *in* B. C. Kirkevold and J. S. Lockard, editors. Behavioral biology of killer whales. Alan R. Liss, New York, New York.

Heise, K., L. G. Barrett-Lennard, E. Saulitis, C. Matkin, and D. Bain. 2003. Examining the evidence for killer whale predation on Steller sea lions in British Columbia. Aquatic Mammals 29:325-334.

Heise, K., G. Ellis, and C. Matkin. 1991. A catalogue of Prince William Sound killer whales. North Gulf Oceanic Society, Homer, Alaska.

Heithaus, M. R. 2001. Shark attacks on bottlenose dolphins (*Tursiops aduncus*) in Shark Bay, Western Australia: attack rate, bite scar frequencies, and attack seasonality. Marine Mammal Science 17:526-539.

Henderson, M. A. and C. C. Graham. 1998. History and status of Pacific salmon in British Columbia. North Pacific Anadromous Fish Commission Bulletin 1:13-22.

Heptner, V. G., K. K. Chapskii, V. A. Arsen'ev, and V. E. Sokolov. 1976. Mammals of the Soviet Union. Volume II, part 3. Pinnipeds and toothed whales: Pinnipedia and Odontoceti. Vysshaya Shkola Publishers, Moscow, Soviet Union. (English translation, 1996, Science Publishers, Lebanon, New Hampshire).

Herman, D. P., D. G. Burrows, P. Wade, J. Durban, R. G. LeDuc, C. Matkin, and M. M. Krahn. 2004. Ecotype classification and prey preferences of eastern North Pacific killer whale populations from fatty acid, stable isotope, and organochlorine analyses of blubber biopsies. Report number SC/56/E14, International Whaling Commission, Cambridge, United Kingdom.

Heyning, J.E. 1988. Presence of solid food in a young killer calf whale (*Orcinus orca*). Marine Mammal Science 4:68-71.

Hildebrand, J. 2004. Appendix 3. Introduction to acoustics. Pages 24-26 *in* Scientific Committee report, 2004. Annex K. Report of the standing working group on environmental concerns. International Whaling Commission, Cambridge, United Kingdom.

Hites, R. A. 2004. Polybrominated diphenyl ethers in the environment and in people: a meta-analysis of concentrations. Environmental Science and Technology 38:945-956.

Hites, R. A., J. A. Foran, S. J. Schwager, B. A. Knuth, M. C. Hamilton, and D. O. Carpenter. 2004. Global assessment of polybrominated diphenyl ethers in farmed and wild salmon. Environmental Science and Technology 38:4945-4949.

Hoelzel, A. R. 1991. Killer whale predation on marine mammals in Punta Norte, Argentina: food sharing, provisioning, and foraging strategy. Behavioral Ecology and Sociobiology 29:297-304.

Hoelzel, A. R. 1993. Foraging behaviour and social group dynamics in Puget Sound killer whales. Animal Behaviour 45:581-591.

Hoelzel, A. R. 2004. Report on killer whale population genetics for the BRT review on the status of the southern resident population. Unpublished report to the BRT.

Hoelzel, A. R. and G. A. Dover. 1991. Genetic differentiation between sympatric killer whale populations. Heredity 66:191-195.

Hoelzel, A. R., M. Dahlheim, and S. J. Stern. 1998. Low genetic variation among killer whales (*Orcinus orca*) in the eastern north Pacific and genetic differentiation between foraging specialists. Journal of Heredity 89:121-128.

Hoelzel, A. R., A. Natoli, M. E. Dahlheim, C. Olavarria, R. W. Baird, and N. A. Black. 2002. Low worldwide genetic diversity in the killer whale (*Orcinus orca*): implications for demographic history. Proceedings of the Royal Society of London, Biological Sciences, Series B 269:1467-1473.

Hong, C.-S., J. Calambokidis, B. Bush, G. H. Steiger, and S. Shaw. 1996. Polychlorinated biphenyls and organochlorine pesticides in harbor seal pups from the inland waters of Washington State. Environmental Science and Technology 30:837-844.

Hooker, S. K. and R. W. Baird. 2001. Diving and ranging behaviour of odontocetes: a methodological review and critique. Mammal Review 31:81-105.

Hoyt, E. 1990. Orca: the whale called killer. 3rd edition. Camden House Publishing, North York, Ontario.

Hoyt, E. 1992. The performing orca -- why the show must stop. Whale and Dolphin Conservation Society, Bath, United Kingdom.

Hoyt, E. 2001. Whale watching 2001: worldwide tourism numbers, expenditures, and expanding socioeconomic benefits. International Fund for Animal Welfare, Yarmouth, Massachusetts.

Hoyt, E. 2002. Whale watching. Pages 1305-1310 *in* W. F. Perrin, B. Würsig, and J. G. M. Thewissen, editors. Encyclopedia of marine mammals. Academic Press, San Diego, California.

International Pacific Halibut Commission. 2002. Assessment of the Pacific halibut stock at the end of 2001. International Pacific Halibut Commission, Seattle, Washington.

Ishida, Y., A. Yano, M. Ban, and M. Ogura. 2001. Vertical movement of a chum salmon *Oncorhynchus keta* in the western North Pacific Ocean as determined by a depth-recording archival tag. Fisheries Science 67:1030-1035.

Ivashin, M. V. 1982. USSR progress report on cetacean research June 1979-May 1980. Report of the International Whaling Commission 32:221-226.

Ivashin, M. V. and L. M. Votrogov. 1981. Killer whales, *Orcinus orca*, inhabiting inshore waters of the Chukotka coast. Report of the International Whaling Commission 31:521.

Iwata, H., S. Tanabe, N. Sakai, and R. Tatsukawa. 1993. Distribution of persistent organochlorines in the oceanic air and surface seawater and the role of ocean on their global transport and fate. Environmental Science and Technology 27:1080-1098.

Jacobsen, J. K. 1986. The behavior of *Orcinus orca* in the Johnstone Strait, British Columbia. Pages 135-185 *in* B. C. Kirkevold and J. S. Lockard, editors. Behavioral biology of killer whales. Alan R. Liss, New York, New York.

Jaffe, D., T. Anderson, D. Covert, R. Kotchenruther, B. Trost, J. Danielson, W. Simpson, T. Berntsen, S. Karlsdottir, D. Blake, J. Harris, G. Carmichael, and I. Uno. 1999. Transport of Asian air pollution to North America. Geophysical Research Letters 26:711-714.

Jarman, W. M., R. J. Norstrom, D. C. G. Muir, B. Rosenberg, M. Simon, and R. W. Baird. 1996. Levels of organochlorine compounds, including PCDDS and PCDFS, in the blubber of cetaceans from the west coast of North America. Marine Pollution Bulletin 32:426-436.

Jefferson, T. A., P. J. Stacey, and R. W. Baird. 1991. A review of killer whale interactions with other marine mammals: predation to co-existence. Mammal Review 21:151-180.

Jeffries, S., H. Huber, J. Calambokidis, and J. Laake. 2003. Trends and status of harbor seals in Washington State: 1978-1999. Journal of Wildlife Management 67:207-218.

Jehl, J. R., Jr., W. E. Evans, F. T. Awbrey, W. S. Drieschmann. 1980. Distribution and geographic variation in the killer whale (*Orcinus orca*) populations of the Antarctic and adjacent waters. Antarctic Journal of the United States 15:161-163.

Jelinski, D. E., C. C. Krueger, and D. A. Duffus. 2002. Geostatistical analyses of interactions between killer whales (*Orcinus orca*) and recreational whale-watching boats. Applied Geography 22:393-411.

Jensen, T., M. van de Bildt, H. H. Dietz, T. H. Andersen, A. S. Hammer, T. Kuiken, and A. Osterhaus. 2002. Another phocine distemper outbreak in Europe. Science 297:209.

Jepson, P. D., M. Arbelo, R. Deaville, I. A. P. Patterson, P. Castro, J. R. Baker, E. Degollada, H. M. Ross, P. Herráez, A. M. Pocknell, F. Rodríguez, F. E. Howie, A. Espinosa, R. J. Reid, J. R. Jaber, V. Martin, A. A. Cunningham, and A. Fernández. 2003. Gas-bubble lesions in stranded cetaceans. Science 425:575-576.

Jepson, P. D., P. M. Bennett, C. R. Allchin, R. J. Law, T. Kuiken, J. R. Baker, E. Rogan, and J. K. Kirkwood. 1999. Investigating potential associations between chronic exposure to polychlorinated biphenyls and infectious disease mortality in harbour porpoises from England and Wales. Science of the Total Environment 243-244:39-348.

Johnson, O. W., W. S. Grant, R. G. Kope, K. Neely, F. W. Waknitz, and R. S. Waples. 1997a. Status review of chum salmon from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-32, U.S. Department of Commerce, Seattle, Washington.

Johnson, T. H., R. Lincoln, G. R. Graves, and R. G. Gibbons. 1997b. Status of wild salmon and steelhead stocks in Washington State. Pages 127-144 *in* D. J. Stouder, P. A. Bisson, and R. J. Naiman, editors.

Pacific salmon & their ecosystems: status and future options. Chapman & Hall, New York, New York.

Jonsgård, Å. and P. B. Lyshoel. 1970. A contribution to the knowledge of the biology of the killer whale *Orcinus orca* (L.) Nytt Magasin for Zoologi 18:41-48.

Kannan, K., J. Koistinen, K. Beckmen, T. Evans, J. F. Gorzelany, K. J. Hansen, P. D. Jones, E. Helle, M. Nyman, and J. P. Giesy. 2001. Accumulation of perfluorooctane sulfonate in marine mammals. Environmental Science and Technology 35:1593-1598.

Kasamatsu, F., K. Matsuoka, and T. Hakamada. 2000. Interspecific relationships in density among the whale community in the Antarctic. Polar Biology 23:466-473.

Kastelein, R. A. and N. Vaughan. 1989. Food consumption, body measurements and weight changes of a female killer whale (*Orcinus orca*). Aquatic Mammals 15:18-21.

Kastelein, R. A., J. Kershaw, E. Berghout, and P. R. Wiepkema. 2003. Food consumption and suckling in killer whales *Orcinus orca* at Marineland Antibes. International Zoo Yearbook 38:204-218.

Kastelein, R. A., S. Walton, D. Odell, S. H. Nieuwstraten, and P. R. Wiepkema. 1989. Food consumption of a female killer whale (*Orcinus orca*). Aquatic Mammals 26:127-131.

Kasuya, T. 1971. Consideration of distribution and migration of toothed whales off the Pacific coast of Japan based on aerial sighting records. Scientific Reports of the Whales Research Institute 23:37-60.

Kasuya, T. 1973. Systematic consideration of recent toothed whales based on the morphology of tympano-periotic bone. Scientific Reports of the Whales Research Institute 25:1-103.

Kasuya, T. and H. Marsh. 1984. Life history and reproductive biology of the short-finned pilot whale, *Globicephala macrorhynchus*, off the Pacific coast of Japan. Report of the International Whaling Commission, Special Issue 6:259-310.

Kennedy, S. 1999. Morbilliviral infections in marine mammals. Journal of Cetacean Research and Management, Special Issue 1:267-273.

Kennedy, S. 2001. Morbillivirus infections in aquatic mammals. Pages 64-76 *in* E. S. Williams and I. K. Barker, editors. Infectious diseases of wild mammals. Iowa State University Press, Ames, Iowa.

Kennedy, S., T. Kuiken, P. D. Jepson, R. Deaville, M. Forsyth, T. Barrett, M. W.G. van de Bildt, A. D. M. E. Osterhaus, T. Eybatov, C. Duck, A. Kydyrmanov, I. Mitrofanov, and S. Wilson. 2000. Mass die-off of Caspian seals caused by canine distemper virus. Emerging Infectious Diseases 6:637-639.

Klinowska, M. 1991. Dolphins, porpoises and whales of the world: the IUCN Red Data Book. IUCN, Gland, Switzerland.

Kope, R. and T. Wainwright. 1998. Trends in the status of Pacific salmon populations Washington, Oregon, California, and Idaho. North Pacific Anadromous Fish Commission Bulletin 1:1-12.

Koski, K. 2004. The Soundwatch Boater Education Program: trends in vessel traffic with southern resident killer whales. The Whale Museum, Friday Harbor, Washington.

Kostow, K. 1997. The status of salmon and steelhead in Oregon. Pages 145-178 *in* D. J. Stouder, P. A. Bisson, and R. J. Naiman, editors. Pacific salmon & their ecosystems: status and future options. Chapman & Hall, New York, New York.

Krahn, M. M., D. G. Burrows, J. E. Stein, P. R. Becker, M. M. Schantz, D. C. G. Muir, T. M. O'Hara, and T. Rowles. 1999. White whales (*Delphinapterus leucas*) from three Alaskan stocks - concentrations and patterns of persistent organochlorine contaminants in blubber. Journal of Cetacean Research and Management 1:239-249.

Krahn, M. M., D. P. Herman, G. M. Ylitalo, C. A. Sloan, D. G. Burrows, R. C. Hobbs, B. A. Mahoney, G. K. Yanagida, J. Calambokidis, and S. E. Moore. 2004b. Stratification of lipids, fatty acids and organochlorine contaminants in blubber of white whales and killer whales. Journal of Cetacean Research and Management 6:175-189.

Krahn, M. M., M. J. Ford, W. F. Perrin, P. R. Wade, R. P. Angliss, M. B. Hanson, B. L. Taylor, G. M. Ylitalo, M. E. Dahlheim, J. E. Stein, and R. S. Waples. 2004a. 2004 status review of southern resident killer whales (*Orcinus orca*) under the Endangered Species Act. NOAA Technical Memorandum NMFS-NWFSC-62, U.S. Department of Commerce, Seattle, Washington.

Krahn, M. M., P. R. Wade, S. T. Kalinowski, M. E. Dahlheim, B. L. Taylor, M. B. Hanson, G. M. Ylitalo, R. P. Angliss, J. E. Stein, and R. S. Waples. 2002. Status review of southern resident killer whales (*Orcinus orca*) under the Endangered Species Act. NOAA Technical Memorandum NMFS-NWFSC-54, U.S. Department of Commerce, Seattle, Washington.

Krahn, M. M., G. M. Ylitalo, D. G. Burrows, J. Calambokidis, S. E. Moore, M. Gosho, P. Gearin, P. D. Plesha, R. L. Brownell, Jr., S. A. Blokhin, K. L. Tilbury, T. Rowles, and J. E. Stein. 2001. Organochlorine contaminant concentrations and lipid profiles in eastern North Pacific gray whales (*Eschrichtius robustus*). Journal of Cetacean Research and Management 3:19-29.

Kriete, B. 1995. Bioenergetics in the killer whale, *Orcinus orca*. Ph.D. thesis, University of British Columbia, Vancouver, British Columbia.

Kruse, S. 1991. The interactions between killer whales and boats in Johnstone Strait, B.C. Pages 149-159 *in* K. Pryor and K. S. Norris, editors. Dolphin societies: discoveries and puzzles. University of California Press, Berkeley, California.

Kuiken, T., U. Hofle, P. M. Bennett, C. R. Allchin, J. K. Kirkwood, J. R. Baker, E. C. Appleby, C. H. Lockyer, M. J. Walton, and M. C. Sheldrick. 1993. Adrenocortical hyperplasia, disease, and chlorinated hydrocarbons in the harbour porpoise (*Phocoena phocoena*). Marine Pollution Bulletin 26:440-446.

Lahvis, G. P., R. S. Wells, D. W. Kuehl, J. L. Stewart, H. L. Rhinehart, and C. S. Via. 1995. Decreased lymphocyte responses in free-ranging bottlenose dolphins (*Tursiops truncatus*) are associated with increased concentrations of PCBs and DDT in peripheral blood. Environmental Health Perspectives 103:67-72.

Landolt, M., D. Kalman, A. Nevissi, G. van Belle, K. Van Ness, and F. Hafer. 1987. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound: final report. NOAA Technical Memorandum NOS OMA 33, National Oceanic and Atmospheric Administration, Rockville, Maryland.

Lang, T. G. 1966. Hydrodynamic analysis of cetacean performance. Pages 410-432 *in* K. S. Norris, editor. Whales, porpoises and dolphins. University of California Press, Berkeley, California.

Langelier, K. M., P. J. Stacey, and R. M. Baird. 1990. Stranded whale and dolphin program of B.C. – 1989 report. Wildlife Veterinary Report 3(1):10-11.

Langer, O. E., F. Hietkamp, and M. Farrell. 2000. Human population growth and the sustainability of urban salmonid streams in the lower Fraser Valley. Pages 349-361 *in* E. E. Knudsen, C. R. Steward, D. D. MacDonald, J. E. Williams, and D. W. Reiser, editors. Sustainable fisheries management: Pacific salmon. Lewis Publishers, Boca Raton, Florida.

Leatherwood, S., R. R. Reeves, W. F. Perrin, and W. E. Evans. 1988. Whales, dolphins, and porpoises of the eastern North Pacific and adjacent arctic waters: a guide to their identification. Dover Publications, New York, New York.

LeDuc, R. G. and R. L. Pitman. 2004. Genetic and morphological evidence supports multiple species of killer whales in Antarctica. Document LJ/04/KW8, Workshop on Shortcomings of Cetacean Taxonomy in Relation to Needs of Conservation and Management, April 30-May 2, 2004, La Jolla, California.

LeDuc, R. G. and B. L. Taylor. 2004. Mitochondrial sequence variation in North Pacific killer whales. Revised Document LJ/04/KW7, Workshop on Shortcomings of Cetacean Taxonomy in Relation to Needs of Conservation and Management, April 30-May 2, 2004, La Jolla, California.

LeDuc R. G., W. F. Perrin, and A. E. Dizon. 1999. Phylogenetic relationships among the delphinid cetaceans based on full cytochrome b sequences. Marine Mammal Science 15:619-648.

Leung, Y. M. 1970. *Cyamus orcina*, a new species of whale louse (Cyamidae, Amphipoda) from a killer whale. Bulletin de l'Institut Français d'Afrique Noire, Série A 32:669-675.

Levin, P.S., R. W. Zabel, and J. G. Williams. 2001. The road to extinction is paved with good intentions: negative association of fish hatcheries with threatened salmon. Proceedings of the Royal Society of London, Biological Sciences, Series B 268:1153-1158.

Lichatowich, J. 1999. Salmon without rivers: a history of the Pacific salmon crisis. Island Press, Washington, D.C.

Lichota, G. B., M. McAdie, and P. S. Ross. 2004. Endangered Vancouver Island marmots (*Marmota vancouverensis*): sentinels of atmospherically delivered contaminants to British Columbia, Canada. Environmental Toxicology and Chemistry 23:402-407.

Lien, J. 2001. The conservation basis for the regulation of whale watching in Canada by the Department of Fisheries and Oceans: a precautionary approach. Canadian Technical Report of Fisheries and Aquatic Sciences 2363:1-38.

Lien, J., G. B. Stenson, and P. W. Jones. 1988. Killer whales (*Orcinus orca*) in waters off Newfoundland and Labrador, 1978-1986. Rit Fiskideildar 11:194-201.

Lindström, G., H. Wingfors, M. Dam, and B. van Bavel. 1999. Identification of 19 polybrominated diphenyl ethers (PBDEs) in long-finned pilot whale (*Globicephala melas*) from the Atlantic. Archives of Environmental Contamination and Toxicology 36:355-363.

Lopez, J. C. and D. Lopez. 1985. Killer whales (*Orcinus orca*) of Patagonia, and their behavior of intentional stranding while hunting nearshore. Journal of Mammalogy 66:181-183.

Love, M. S., M. Yaklovich, and L. Thorsteinson. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley, California.

Lowry, L. F., R. R. Nelson, and K. J. Frost. 1987. Observations of killer whales, *Orcinus orca*, in western Alaska: sightings, strandings, and predation on other marine mammals. Canadian Field-Naturalist 101:6-12.

Ljungblad, D. K., B. Würsig, S. L. Swartz, and J. M. Keene. 1988. Observations on the behavioral responses
of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic 41:183-194.

Llaave et al. 2002. Need citation.

Lund, B. O. 1994. In vitro adrenal bioactivation and effects on steroid metabolism of DDT, PCBs and their metabolites in the gray seal (*Halichoerus grypus*). Environmental Toxicology and Chemistry 13:911-917.

Mahnken, C., G. Ruggerone, W. Waknitz, and T. Flagg. 1998. A historical perspective on salmonid production from Pacific rim hatcheries. North Pacific Anadromous Fish Commission Bulletin 1:38-53.

Malme, C. I., P. R. Miles, C. W. Clark, P. Tyack, and J.E. Bird. 1983. Investigations on the potential effects of underwater noise from petroleum industry activities on migrating whale behavior. BBN Report 5366, Bolt Beranek and Newman, Inc., Cambridge, Massachusetts, for U.S. Minerals Management Service, Anchorage, Alaska, NTIS PB86-174174.

Malme, C. I., P. R. Miles, C. W. Clark, P. Tyack, and J. E. Bird. 1984. Investigations on the potential effects of underwater noise from petroleum industry activities on migrating whale behavior/Phase II: January 1984 migration. BBN Report 5586, Bolt Beranek and Newman, Inc., Cambridge, Massachusetts, for U.S. Minerals Management Service, Anchorage, Alaska, NTIS PB86-218377.

Malme, C. I., B. Würsig, J. E. Bird, and P. Tyack. 1988. Observations of feeding gray whale responses to controlled industrial noise exposure. Pages 55-73 *in* W. M. Sackinger, M. O. Jeffries, J. L. Imm, and S. D. Treacy, editors. Port and ocean engineering under arctic conditions, Volume III. University of Alaska,
Fairbanks, Alaska.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78:1069-1079.

Marine Mammal Monitoring Project. 2002. Annual report, 2001-2002. Marine Mammal Monitoring Project, Victoria, British Columbia.

Marsili, L., M. C. Fossi, D. S. Notarbartolo, M Zanardelli, B. Nani, S. Panigada, and S. Focardi. 1998. Relationship between organochlorine contaminants and mixed function oxidase activity in skin biopsy specimens of Mediterranean fin whales (*Balaenoptera physalus*). Chemosphere 37:1501-1510.

Matkin, C. O. 1986. Killer whale interactions with the sablefish longline fishery in Prince William Sound, Alaska 1985, with comments on the Bering Sea. Marine Mammal Division, National Marine Fisheries Service, Juneau, Alaska.

Matkin, C. 1994. An observer's guide to the killer whales of Prince William Sound. Prince William Sound Books, Valdez, Alaska.

Matkin, C. O. and S. Leatherwood. 1986. General biology of the killer whale, *Orcinus orca*: a synopsis of knowledge. Pages 35-68 *in* B. C. Kirkevold and J. S. Lockard, editors. Behavioral biology of killer whales. Alan R. Liss, New York, New York.

Matkin, C. O. and E. L. Saulitis. 1994. Killer whale (*Orcinus orca*) biology and management in Alaska. Contract No. T75135023, Marine Mammal Commission, Washington, D.C.

Matkin, C. O. and E. Saulitis. 1997. Restoration notebook: killer whale (*Orcinus orca*). Exxon Valdez Oil Spill Trustee Council, Anchorage, Alaska.

Matkin, C.O., G. E. Ellis, M. E. Dahlheim, and J. Zeh. 1994. Status of killer whales in Prince William Sound, 1984-1992. Pages 141-162 *in* T. R. Loughlin, editor. Marine mammals and the *Exxon Valdez*. Academic Press, San Diego, California.

Matkin, C. O., G. Ellis, P. Olesiuk, and E. Saulitis. 1999b. Association patterns and inferred genealogies of resident killer whales, *Orcinus orca*, in Prince William Sound, Alaska. Fishery Bulletin 97:900-919.

Matkin, C., G. Ellis, E. Saulitis, L. Barrett-Lennard, and D. Matkin. 1999a. Killer whales of southern Alaska. North Gulf Oceanic Society, Homer, Alaska.

Matkin, C. O., D. R. Matkin, G. M. Ellis, E. Saulitis, and D. McSweeney. 1997. Movements of resident killer whales in southeastern Alaska and Prince William Sound, Alaska. Marine Mammal Science 13:469-475.

Matkin, C. O., G. Ellis, L. Barrett-Lennard, H. Yurk, E. Saulitis, D. Scheel, P. Olesiuk, and G. Ylitalo. 2003. Photographic and acoustic monitoring of killer whales in Prince William Sound and Kenai Fjords. Restoration Project 030012 Final Report, *Exxon Valdez* Oil Spill Restoration Project, North Gulf Oceanic Society, Homer, Alaska.

McCallum, H., D. Harvell, and A. Dobson. 2003. Rates of spread of marine pathogens. Ecology Letters 6:1062-1067.

McCauley, R. D., J. Fewtrell, and A. N. Popper. 2003. High intensity anthropogenic sound damages fish ears. Journal of the Acoustical Society of America 113:638-642.

McComb, K., C. Moss, S. M. Durant, L. Baker, and S. Sayialel. 2001. Matriarchs as repositories of social knowledge in African elephants. Science 292:491-494.

Meacham, P. 2001. Washington State aquatic nuisance species management plan. Washington Department of Fish and Wildlife, Olympia, Washington.

Mead, J. G. 1975. Anatomy of the external nasal passages and facial complex in the Delphinidae. (Mammalia: Cetacea). Smithsonian Contributions to Zoology 207:1-72.

Mearns, A. J. 2001. Long-term contaminant trends and patterns in Puget Sound, the Straits of Juan de Fuca, and the Pacific Coast. *In* T. Droscher, editor. Proceedings of the 2001 Puget Sound Research Conference. Puget Sound Action Team. Olympia, Washington.

Mikhalev, Y. A., M. V. Ivashin, V. P. Savusin, and F. E. Zelenaya. 1981. The distribution and biology of killer whales in the Southern Hemisphere. Report of the International Whaling Commission 31:551-566.

Miller, P. J. O. 2002. Mixed-directionality of killer whale stereotyped calls: a direction of movement cue? Behavioral Ecology and Sociobiology 52:262-270.

Miller, P. J. O. and D. E. Bain. 2000. Within-pod variation in the sound production of a pod of killer whales, *Orcinus orca*. Animal Behaviour 60:617-628.

Miller, P. J. O., A. D. Shapiro, P. L. Tyack, and A. R. Solow. 2004. Call-type matching in vocal exchanges of free-ranging resident killer whales, *Orcinus orca*. Animal Behaviour 67:1099-1107.

Miller, W. G., L. G. Adams, T. A. Ficht, N. F. Cheville, J. P. Payeur, D. R. Harley, C. House, and S. H. Ridgway. 1999. *Brucella*-induced abortions and infection in bottlenose dolphins (*Tursiops truncatus*). Journal of Zoo and Wildlife Medicine 30:100-110.

Mills, T. J., D. R. McEwan, and M. R. Jennings. 1997. California salmon and steelhead: beyond the crossroads. Pages 91-111 *in* D. J. Stouder, P. A. Bisson, and R. J. Naiman, editors. Pacific salmon & their ecosystems: status and future options. Chapman & Hall, New York, New York.

Mintz, J. D. and R. J. Filadelpho. 2004a. Estimating Navy and non-Navy vessel traffic in areas of interest. Report CRM D0010124.A2, CNA Corporation, Alexandria, Virginia.

Mintz, J. D. and R. J. Filadelpho. 2004b. Vessel traffic and radiated noise in the Pacific Northwest. Report CME D0010607.A1, CNA Corporation, Alexandria, Virginia.

Mitchell, E. 1975. Porpoise, dolphin and small whale fisheries of the world: status and problems. IUCN Monograph No. 3, International Union for Conservation of Nature and Natural Resources, Morges, Switzerland.

Mitchell, E. and R. R. Reeves. 1988. Records of killer whales in the western North Atlantic, with emphasis on eastern Canadian waters. Rit Fiskideildar 11:161-193.

Miyashita, T., H. Kato, and T. Kasuya. 1995. Worldwide map of cetacean distribution based on Japanese sighting data (Volume 1). National Research Institute of Far Seas Fisheries, Shimizu, Shizuoka, Japan.

Miyazaki, N. 1989. Notes on the school composition of killer whales in the Southern Hemisphere. Bulletin of the National Museum of Tokyo, Series A 15:53-59.

Mobley, J. R., Jr., L. Mazzuca, A. S. Craig, M. W. Newcomer, and S. S. Spitz. 2001. Killer whales (*Orcinus orca*) sighted west of Ni'ihau, Hawai'i. Pacific Science 55:301-303.

Møhl B., W. W. L. Au, J. Pawloski, and P. E. Nachtigall. 1999. Dolphin hearing: relative sensitivity as a function of point of application of a contact sound source in the jaw and head region. Journal of the Acoustical Society of America 105:3421-3424.

Monterey Bay Whale Watch. 2003. Southern resident killer whales sighted in Monterey Bay. <http://www.montereybaywhalewatch.com/Features/feat0303.htm>.

Morejohn, G. V. 1968. A killer whale-gray whale encounter. Journal of Mammalogy 49:327-328.

Morin, P. A., R. G. LeDuc, K. M. Robertson, N. M. Hedrick, W. Perrin, P. Wade, and B. L. Taylor. 2004. Genetic analysis of killer whale (*Orcinus orca*) historic samples for evidence of southern resident haplotypes along the western U.S. Unpublished report to BRT.

Morton, A. B. 1990. A quantitative comparison of the behavior of resident and transient forms of the killer whale off the central British Columbia coast. Report of the International Whaling Commission, Special Issue 12:245-248.

Morton, A. B. and H. K. Symonds. 2002. Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. ICES Journal of Marine Science 59:71-80.

Morton, A., R. Routledge, C. Peet, and A. Ladwig. 2004. Sea lice (*Lepeophtheirus salmonis*) infection rates on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon in the nearshore marine environment of British Columbia, Canada. Canadian Journal of Fisheries and Aquatic Sciences 61:147-157.

Mos, L., P. S. Ross, D. McIntosh, and S. Raverty. 2003. Canine distemper virus in river otters in British Columbia as an emergent risk for coastal pinnipeds. Veterinary Record 152:237-239.

Muir, D. C. G., R. Wagemann, B. T. Hargrave, D. J. Thomas, D. B. Peakall, and R. J. Norstrom. 1992. Arctic marine ecosystem contamination. Science of the Total Environment 122:75-134.

Murata, K., K. Mizuta, K. Imazu, F. Terasawa, M. Taki, and T. Endoh. 2004. The prevalence of *Toxoplasma gondii* antibodies in wild and captive cetaceans from Japan. Journal of Parasitology 90:896-898.

Murie, O. J. 1959. Fauna of the Aleutian Islands and Alaska Peninsula. North American Fauna. No. 61, U. S. Fish and Wildlife Service, Washington, D.C.

Myers, J. M., R. J. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F. W. Waknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. Status review of chinook salmon from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-35, U.S. Department of Commerce, Seattle, Washington.

Nash, C.E., editor. 2001. The net-pen salmon farming industry in the Pacific Northwest. NOAA Technical Memorandum NMFS-NWFSC-49, U.S. Department of Commerce, Seattle, Washington.

National Marine Fisheries Service. 1993. Endangered fish and wildlife: gray whale. Federal Register 58:3121-3135.

National Marine Fisheries Service. 2002. Endangered and threatened wildlife and plants: 12-month finding for a petition to list southern resident killer whales as threatened or endangered under the Endangered Species Act (ESA). Federal Register 67(126):44133-44138.

National Marine Fisheries Service. 2003a. Status review of the AT1 group of killer whales from the Prince William Sound and Kenai Fjords area. National Marine Fisheries Service, Seattle, Washington.

National Marine Fisheries Service. 2003b. Regulations governing the taking and importing of marine mammals; eastern North Pacific southern resident killer whales. Federal Register 68(103):31980-31983.

National Marine Fisheries Service. 2004a. Designation of the AT1 group of transient killer whales as a depleted stock under the Marine Mammal Protection Act (MMPA). Federal Register 69(107):31321-31324.

National Marine Fisheries Service. 2004b. Endangered and threatened wildlife and plants: proposed threatened status for southern resident killer whales. Federal Register 69(245):76673-76682.

National Marine Fisheries Service. 2004c. Listing endangered and threatened species and designating critical habitat: petitions to list the Cherry Point stock of Pacific herring as an endangered or threatened species. Federal Register 69(153):48455-48460.

National Marine Fisheries Service. 2004d. Assessment of acoustic exposures on marine mammals in conjunction with *USS Shoup* active sonar transmissions in the eastern Strait of Juan de Fuca and Haro Strait, Washington. Office of Protected Resources, National Marine Fisheries Service, Silver Spring, Maryland.

National Marine Fisheries Service. 2004e. Interim endangered and threatened species recovery planning guidance. <http://www.nmfs.noaa.gov/pr/PR3/recover_planning.html>.

National Research Council. 1996. Upstream: salmon and society in the Pacific Northwest. National Academy Press, Washington, D.C.

National Research Council. 2003. Ocean noise and marine mammals. National Academies Press, Washington, D.C.

Navata et al. 2002. Need citation.

Neel, J., C. Hart, D. Lynch, S. Chan, and J. Harris. 1997. Oil spills in Washington State: a historical analysis. Publication No. 97-252, Department of Ecology, Olympia, Washington.

Nehlsen, W. 1997. Pacific salmon status and trends – a coastwide perspective. Pages 41-50 *in* D. J. Stouder, P. A. Bisson, and R. J. Naiman, editors. Pacific salmon & their ecosystems: status and future options. Chapman & Hall, New York, New York.

Nemoto, T., P. B. Best, K. Ishimaru, and H. Takano. 1980. Diatom films on whales in South African waters. Scientific Reports of the Whales Research Institute 32:97-103.

Newby, T. C. 1973. Changes in the Washington State harbor seal population, 1942-1972. Murrelet 54:4-6.

Nichol, L. M. and D. M. Shackleton. 1996. Seasonal movements and foraging behaviour of northern resident killer whales (*Orcinus orca*) in relation to the inshore distribution of salmon (*Oncorhynchus* spp.) in British Columbia. Canadian Journal of Zoology 74:983-991.

Nicholas, J. W. and D. G. Hankin. 1989. Chinook salmon populations in Oregon coastal basins: description of life histories and assessment of recent trends in run strengths. Oregon Department of Fish and Wildlife, Corvallis, Oregon.

Nickelson, T. E., J. W. Nicholas, A. M. McGie, R. B. Liday, D. L. Bottom, R. J. Kaiser, and S. E. Jacobs. 1992. Status of anadromous salmonids in Oregon coastal basins. Oregon Department of Fish and Wildlife, Corvallis, Oregon.

Nieukirk, S. L., K. M. Stafford, D. K. Mellinger, R. P Dziak, and C. G. Fox. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. Journal of the Acoustical Society of America 115:1832-1843.

Nishiwaki, M. 1972. General biology. Pages 3-204 *in* S. H. Ridgway, editor. Mammals of the sea: biology and medicine. Thomas, Springfield, Illinois.

Nishiwaki, M. and C. Handa. 1958. Killer whales caught in the coastal waters off Japan for recent 10 years. Scientific Reports of the Whales Research Institute 13:85-96.

Norman, S. A., C. E. Bowlby, M. S. Brancato, J. Calambokidis, D. Duffield, P. J. Gearin, T. A. Gornall, M. E. Gosho, B. Hanson, J. Hodder, S. J. Jeffries, B. Lagerquist, D. M. Lanbourn, B. Mate, B. Norberg, R. W. Osborne, J. A. Rash, S. Riemer, and J. Scordino. 2004. Cetacean strandings in Oregon and Washington between 1930 and 2002. Journal of Cetacean Research and Management 6:87-99.

Norris, K. S. and J. H. Prescott. 1961. Observations of Pacific cetaceans of Californian and Mexican waters. University of California Publications in Zoology 63:291-402.

Northcote, T. G. and D. Y. Atagi. 1997. Pacific salmon abundance trends in the Fraser River watershed compared with other British Columbia River systems. Pages 199-219 *in* D. J. Stouder, P. A. Bisson, and R. J. Naiman, editors. Pacific salmon & their ecosystems: status and future options. Chapman & Hall, New York, New York.

Northwest Power Planning Council. 1986. Council staff compilation of information on salmon and steelhead losses in the Columbia River basin. Northwest Power Planning Council, Portland, Oregon.

Ohsumi, S. 1975. Review of Japanese small-type whaling. Journal of the Fisheries Research Board of Canada 32:1111-1121.

Øien, N. 1988. The distribution of killer whales (*Orcinus orca*) in the North Atlantic based on Norwegian catches, 1938-1981, and incidental sightings, 1967-1987. Rit Fiskideildar 11:65-78.

Olesiuk, P. F. 1999. An assessment of the status of harbour seals (*Phoca vitulina*) in British Columbia. Canadian Stock Assessment Secretariat Research Document 99/33, Department of Fisheries and Oceans, Ottawa, Ontario.

Olesiuk, P. F., M. A. Bigg, and G. M. Ellis. 1990a. Life history and population dynamics of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. Report of the International Whaling Commission, Special Issue 12:209-243.

Olesiuk, P. F., M. A. Bigg, and G. M. Ellis. 1990b. Recent trends in the abundance of harbour seals, *Phoca vitulina*, in British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 47:992-1003.

Olesiuk, P. F., L. M. Nichol, M. J. Sowden, and J. K. B. Ford. 2002. Effect of the sound generated by an acoustic harassment device on the relative abundance and distribution of harbor porpoises (*Phocoena phocoena*) in Retreat Passage, British Columbia. Marine Mammal Science 18:843-862.

Olson, A. F. and T. P. Quinn. 1993. Vertical and horizontal movements of adult chinook salmon, *Oncorhynchus tshawytscha*, in the Columbia River. Fishery Bulletin 91:171-178.

Olson, J. M. 1998. Temporal and spatial distribution patterns of sightings of southern community and transient orcas in the inland waters of Washington and British Columbia. M.S. thesis, Western Washington University, Bellingham, Washington.

O'Neill, S. M. and J. E. West. 2001. Exposure of Pacific herring (*Clupea pallasi*) to persistent organic pollutants in Puget Sound and the Georgia Basin. *In* T. Droscher, editor. Proceedings of the 2001 Puget Sound Research Conference. Puget Sound Action Team. Olympia, Washington.

O'Neill, S. M., J. E. West, and S. Quinell. 1995. Contaminant monitoring in fish: overview of the Puget Sound Ambient Monitoring Program fish task. Pages 35-50 *in* Puget Sound Research '95 Proceedings. Puget Sound Water Quality Authority, Olympia, Washington.

O'Neill, S. M., J. E. West, and J. C. Hoeman. 1998. Spatial trends in the concentration of polychlorinated biphenyls (PCBs) in chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) in Puget Sound and factors affecting PCB accumulation: results from the Puget Sound Ambient Monitoring Program. Pages 312-328 *in* Puget Sound Research '98 Proceedings. Puget Sound Water Quality Authority, Seattle, Washington.

Ono, M., N. Kannan, T. Wakimoto, and R. Tatsukawa. 1987. Dibenzofurans a greater global pollutant than dioxins?: evidence from analyses of open ocean killer whale. Marine Pollution Bulletin 18:640-643.

OrcaInfo. 1999. Orcas in captivity. <http://members.aol.com/orcainfo/index.htm>.

Osborne, R. W. 1986. A behavioral budget of Puget Sound killer whales. Pages 211-249 *in* B. C. Kirkevold and J. S. Lockard, editors. Behavioral biology of killer whales. Alan R. Liss, New York, New York.

Osborne, R. W. 1991. Trends in killer whale movements, vessel traffic, and whale watching in Haro Strait. Pages 672-688 *in* Puget Sound Research '91 Proceedings. Puget Sound Water Quality Authority, Olympia, Washington.

Osborne, R. W. 1999. A historical ecology of Salish Sea "resident" killer whales (*Orcinus orca*): with implications for management. Ph.D. thesis, University of Victoria, Victoria, British Columbia.

Osborne, R., K. Koski, and R. Otis. 2002. Trends in whale watching traffic around southern resident killer whales. The Whale Museum, Friday Harbor, Washington.

Osborne, R. W., K. L. Koski, R. E. Tallmon, and S. Harrington. 1999. Soundwatch 1999 final report. Soundwatch, Roche Harbor, Washington.

O'Shea, T. J. 1999. Environmental contaminants and marine mammals. Pages 485-563 *in* J. E. Reynolds III and S. A. Rommel, editors. Biology of marine mammals. Smithsonian Institution Press, Washington, D.C.

O'Shea, T. J. 2000a. PCBs not to blame. Science 288:1965-1966.

O'Shea, T. J. 2000b. Cause of seal die-off in 1988 is still under debate. Science 290:1097-1098.

O'Shea, T. J. and A. Aguilar. 2001. Cetacea and Sirenia. Pages 427-496 *in* R. F. Shore and B. A. Rattner, editors. Ecotoxicology of wild mammals. John Wiley & Sons, Chichester, United Kingdom.

Oskam, I. C., E. Ropstad, E. Dahl, E. Lie, A. E. Derocher, Ø. Wiig, S. Larsen, R. Wiger, and J. U. Skaare. 2003. Organochlorines affect the major androgenic hormone, testosterone, in male polar bears (*Ursus maritimus*) at Svalbard. Journal of Toxicology and Environmental Health, Part A 66:2119–2139.

Palo, G. J. 1972. Notes on the natural history of the killer whale *Orcinus orca* in Washington State. Murrelet 53:22-24.

Palsson, W. A., J. Beam, S. Hoffmann, and P. Clarke. 2004. Fish without borders: trends in the status and distribution of groundfish in the transboundary waters of Washington and British Columbia. *in* T. W.

Droscher and D. A. Fraser, editors. Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. <http://www.psat.wa.gov/Publications/03_proceedings/start.htm>.

Perrin, W. F. 1989. Dolphins, porpoises, and whales: an action plan for the conservation of biological diversity: 1988-1992. IUCN, Gland, Switzerland.

Perrin, W. 2004. Nomenclature of killer whales. Document LJ/04/KW3, Workshop on Shortcomings of Cetacean Taxonomy in Relation to Needs of Conservation and Management, April 30-May 2, 2004, La Jolla, California.

Perrin, W. F. and J. R. Geraci. 2002. Stranding. Pages 1192-1197 *in* W. F. Perrin, B. Würsig, and J. G. M. Thewissen, editors. Encyclopedia of marine mammals. Academic Press, San Diego, California.

Perrin, W. F. and S. B. Reilly. 1984. Reproductive parameters of dolphins and small whales of the family Delphinidae. Report of the International Whaling Commission, Special Issue 6:97-134.

Pess, G. R., D. R. Montgomery, T. J. Beechie, and L. Holsinger. 2003. Anthropogenic alterations to the biogeography of Puget Sound salmon. Pages 129-154 *in* D. R. Montgomery, S. Bolton, D. B. Booth, and L. Wall, editors. Restoration of Puget Sound Rivers. University of Washington Press, Seattle, Washington.

Petras, E. 2003. A review of marine mammal deterrents and their possible applications to limit killer whale (*Orcinus orca*) predation on Steller sea lions (*Eumetopias jubatus*). AFSC Processed Report 2003-02, Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington.

Pierce, D. J., M. Alexandersdottir, S. J. Jeffries, P. Erstad, W. Beattie, and A. Chapman. 1996. Interactions of marbled murrelets and marine mammals with the 1994 Puget Sound sockeye gill net fishery. Washington Department of Fish and Wildlife, Olympia, Washington.

Pike, G. C. and I. B. MacAskie. 1969. Marine mammals of British Columbia. Bulletin of the Fisheries Research Board of Canada 171:1-54.

Pitman, R. L. and P. H. Dutton. 2004. Killer whale predation on a leatherback turtle in the northeast Pacific. Pacific Science 58:497-498.

Pitman, R. L. and P. Ensor. 2003. Three forms of killer whales (*Orcinus orca*) in Antarctic waters. Journal of Cetacean Research and Management 5:131-139.

Pitman, R. L., L. T. Balance, S. I. Mesnick, and S. J. Chivers. 2001. Killer whale predation on sperm whales: observations and implications. Marine Mammal Science 17:494-507.

Pitman, R. L., S. O'Sullivan, and B. Mase. 2003. Killer whales (*Orcinus orca*) attack a school of pantropical spotted dolphins (*Stenella attenuata*) in the Gulf of Mexico. Aquatic Mammals 29:321-324.

Puget Sound Action Team. 2004. 2005-2007 Puget Sound conservation and recovery plan. Puget Sound Action Team, Olympia, Washington.

Puget Sound Action Team. 2005. State of the sound 2004. Puget Sound Action Team, Olympia, Washington.

Puget Sound Water Quality Action Team. 2000. Puget Sound water quality management plan. Puget Sound Water Quality Action Team, Olympia, Washington.

Pyper, B. J. and R. M. Peterman. 1999. Relationship among adult body length, abundance, and ocean temperature for British Columbia and Alaska sockeye salmon (*Oncorhynchus nerka*), 1967-1997. Canadian Journal of Fisheries and Aquatic Sciences 56:1716-1720.

Quinn, T. P. and B. A. terHart. 1987. Movements of adult sockeye salmon (*Oncorhynchus nerka*) in British Columbia coastal waters in relation to temperature and salinity stratification: ultrasonic telemetry results. Canadian Special Publication of Fisheries and Aquatic Sciences 96:61-77.

Quinn, T. P., J. Peterson, and V. F. Gallucci. 2001. Temporal changes in body length, weight and fecundity of coho salmon (*Oncorhynchus kisutch*) from the University of Washington hatchery, Puget Sound. *In* T. Droscher, editor. Proceedings of the 2001 Puget Sound Research Conference. Puget Sound Action Team. Olympia, Washington.

Quinn, T. P., B. A. terHart, and C. Groot. 1989. Migratory orientation and vertical movements of homing adult sockeye salmon, *Oncorhynchus nerka*, in coastal waters. Animal Behaviour 37:587-599.

Raverty, S. A. and J. K. Gaydos. 2004. Killer whale necropsy and disease testing protocol. <http://mehp.vetmed.ucdavis.edu/pdfs/orcanecropsyprotocol.pdf >.

Rayne, S., M. G. Ikonomou, P. S. Ross, G. M. Ellis, and L. G. Barrett-Lennard. 2004. PBDEs, PBBs, and PCNs in three communities of free-ranging killer whales (*Orcinus orca*) from the northeastern Pacific Ocean. Environmental Science and Technology 38:4293-4299.

Reddy et al. 2001. Need citation.

Reed, J. M., D. D. Murphy, and P. F. Brussard. 1998. Efficacy of population viability analysis. Wildlife Society Bulletin 26:244-251.

Reeves, R. R. and S. Leatherwood. 1994. Dolphins, porpoises, and whales: 1994-1998 action plan for the conservation of cetaceans. IUCN, Gland, Switzerland.

Reeves, R. R. and E. Mitchell. 1988a. Killer whale sightings and takes by American pelagic whalers in the North Atlantic. Rit Fiskideildar 11:7-23.

Reeves, R. R. and E. Mitchell. 1988b. Distribution and seasonality of killer whales in the eastern Canadian Arctic. Rit Fiskideildar 11:136-160.

Reeves, R. R., S. Leatherwood, G. S. Stone, and L. G. Eldredge. 1999. Marine mammals in the area served by the South Pacific Regional Environmental Programme (SPREP). South Pacific Regional Environmental Programme, Apia, Samoa.

Reeves, R. R., W. F. Perrin, B. L. Taylor, C. S. Baker, and S. L. Mesnick, editors. 2004. Report of the workshop on shortcomings of cetacean taxonomy in relation to needs of conservation and management, 28 April-2 May 2004, La Jolla, California. NOAA Technical Memorandum NMFS-SWFSC-363, U.S. Department of Commerce, La Jolla, California.

Reeves, R. R., B. D. Smith, E. A. Crespo, and G. Notarbartolo di Sciara. 2003. Dolphins, whales and porpoises: 2002-2010 conservation action plan for the world's cetaceans. IUCN/SSC Cetacean Specialist Group, IUCN, Gland, Switzerland and Cambridge, Unitied Kingdom.

Reeves, R. R., B. S. Stewart, P. J. Clapham, and J. A. Powell. 2002. Guide to the marine mammals of the world. Alfred A. Knopf, New York, New York.

Reidarson, T. H., J. McBain, C. House, D. P. King, J. L. Stott, A. Krafft, J. K. Taubenberger, J. Heyning, and T. P. Lipscomb. 1998. Morbillivirus infection in stranded common dolphins from the Pacific Ocean. Journal of Wildlife Diseases 34:771-776.

Reijnders, P. J. H. 1986. Reproductive failure in common seals feeding on fish from polluted coastal waters. Nature 324:456-457.

Reijnders, P. J. H. 2003. Reproductive and developmental effects of environmental organochlorines on marine mammals. Pages 55-66 *in* J. G. Vos, G. D. Bossart, M. Fournier, and T. J. O'Shea, editors. Toxicology of marine mammals. Taylor & Francis, London.

Reijnders, P. J. H. and A. Aguilar. 2002. Pollution and marine mammals. Pages 948-957 *in* W. F. Perrin, B. Würsig, and J. G. M. Thewissen, editors. Encyclopedia of marine mammals. Academic Press, San Diego, California.

Reisenbichler, R. R. 1997. Genetic factors contributing to declines in anadromous salmonids in the Pacific Northwest. Pages 223-244 *in* D. J. Stouder, P. A. Bisson, and R. J. Naiman, editors. Pacific salmon & their ecosystems: status and future options. Chapman & Hall, New York, New York.

Reisenbichler, R. R. and S. P. Rubin. 1999. Genetic changes from artificial propagation of Pacific salmon affect the productivity and viability of supplemented populations. ICES Journal of Marine Science 56:459-466.

Reyes, L. M. and P. García-Borboroglu. 2004. Killer whale (*Orcinus orca*) predation on sharks in Patagonia, Argentina: a first report. Aquatic Mammals 30:376-379.

Rice, D. W. 1968. Stomach contents and feeding behavior of killer whales in the eastern North Pacific. Norsk Hvalfangst-Tidende 57:35-38.

Rice, D. W. 1974. Whales and whale research in the eastern North Pacific. Pages 170-195 *in* W. E. Schevill, editor. The whale problem: a status report. Harvard University Press, Cambridge, Massachusetts.

Rice, D. W. 1998. Marine mammals of the world: systematics and distribution. Special Publication No. 4, Society for Marine Mammals, Lawrence, Kansas.

Rice, D. W. and A. A. Wolman. 1971. The life history and ecology of the gray whale (*Eschrichtius robustus*). American Society of Mammalogists Special Publication 3:1-142.

Rice, F. H. and G. S. Saayman. 1987. Distribution and behaviour of killer whales (*Orcinus orca*) off the coasts of southern Africa. Investigations on Cetacea 20:231-250.

Richardson, W. J., C. R. Greene, Jr., C. I. Malme, and D. H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, California.

Riddell, B. E. 1993. Spatial organization of Pacific salmon: what to conserve? Pages 23-41 *in* J. G. Cloud and G. H. Thorgaard, editors. Genetic conservation of salmonid fishes. Plenum Press, New York, New York.

Riddell, B. 2004. Pacific salmon resources in central and north coast British Columbia. Pacific Fisheries Resource Conservation Council, Vancouver, British Columbia.

Ridgway, S. and M. Reddy. 1995. Residue levels of several organochlorines in *Tursiops truncatus* milk collected at varied stages of lactation. Marine Pollution Bulletin 30:609-614.

Robeck, T. R., A. L. Schneyer, J. F. McBain, L. M. Dalton, M. T. Walsh, N. M. Czekala, and D. C. Kraemer. 1993. Analysis of urinary immunoreactive steroid metabolites and gonadotropins for characterization of the estrous cycle, breeding period, and seasonal estrous activity of the killer whale (*Orcinus orca*). Zoo Biology 12:173-187.

Roberts, J. C., Jr., R. C. Boice, R. L. Brownell, Jr., and D. H. Brown. 1965. Spontaneous atherosclerosis in Pacific toothed and baleen whales. Pages 151-155 *in* J. C. Roberts, Jr. and R. Straus, editors. Comparative atherosclerosis: the morphology of spontaneous and induced atherosclerotic lesions in animals and its relation to human disease. Harper and Row, New York, New York.

Rose, N. A. 1992. The social dynamics of male killer whales, *Orcinus orca*, in Johnstone Strait, British Columbia. Ph.D thesis, University of California, Santa Cruz, California.

Ross, P. S. 2002. The role of immunotoxic environmental contaminants in facilitating the emergence of infectious diseases in marine mammals. Human and Ecological Risk Assessment 8:277-292.

Ross, P. S., R. L. de Swart, R. F. Addison, H. van Loveren, J. G. Vos, and A. D. M. E. Osterhaus. 1996a. Contaminant-induced immunotoxicity in harbor seals: wildlife at risk? Toxicology 112:157-169.

Ross, P. S., R. L. de Swart, P. J. H. Reijnders, H. V. Loveren, J. G. Vos, and A. D. M. E. Osterhaus. 1995. Contaminant-related suppression of delayed-type hypersensitivity and antibody responses in harbor seals fed herring from the Baltic Sea. Environmental Health Perspectives 103:162-167.

Ross, P. S., R. L. de Swart, H. van Loveren, A. D. M. E. Osterhaus, and J. G. Vos. 1996b. The immuntoxicity of environmental contaminants to marine wildlife: a review. Annual Review of Fish Diseases 6:151-165.

Ross, P. S., G. M. Ellis, M. G. Ikonomou, L. G. Barrett-Lennard, and R. F. Addison. 2000a. High PCB concentrations in free-ranging Pacific killer whales, *Orcinus orca*: effects of age, sex and dietary preference. Marine Pollution Bulletin 40:504-515.

Ross, P. S., S. J. Jeffries, M. B. Yunker, R. F. Addison, M. G. Ikonomou, and J. C. Calambokidis. 2004. Harbor seals (*Phoca vitulina*) in British Columbia, Canada, and Washington State, USA, reveal a combination of local and global polychlorinated biphenyl, dioxin, and furan signals. Environmental Toxicology and Chemistry 23:157-165.

Ross, P. S. J. G. Vos, L. S. Birnbaum, and A. D. M. E. Osterhaus. 2000b. PCBs are a health risk for humans and wildlife. Science 289:1878-1879.

Ruggerone, G. T., T. P. Quinn, I. A. McGregor, and T. D. Wilkinson. 1990. Horizontal and vertical movements of adult steelhead trout, *Oncorhynchus mykiss*, in the Dean and Fisher channels, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 47:1963-1969.

Samaras, W. F. 1989. New host record for the barnacle *Cryptolepas rhachianecti* Dall, 1872 (Balanomorpha: Coronulidae). Marine Mammal Science 5:84-87.

Saulitis, E., C. Matkin, L. Barrett-Lennard, K. Heise and G. Ellis. 2000. Foraging strategies of sympatric killer whale (*Orcinus orca*) populations in Prince William Sound, Alaska. Marine Mammal Science 16:94-109.

Scammon, C. M. 1874. The marine mammals of the northwestern coast of North America, together with an account of the American whale-fishery. J. H. Carmany and Company, San Francisco, California.

Scheel, D., C. O. Matkin, and E. Saulitis. 2001. Distribution of killer whale pods in Prince William Sound, Alaska 1984-1996. Marine Mammal Science 17:555-569.

Scheffer, T. H. 1928. Precarious status of the seal and sea-lion on our northwest coast. Journal of Mammalogy 9:10-16.

Scheffer, V. B. 1967. The killer whale. Pacific Search 1(7):2.

Scheffer, V. B. 1969. Marks on the skin of a killer whale. Journal of Mammalogy 50:151.

Scheffer, V. B. and J. W. Slipp. 1948. The whales and dolphins of Washington State with a key to the cetaceans of the west coast of North America. American Midland Naturalist 39:257-337.

Schevill, W. E. and W. A. Watkins. 1966. Sound structure and directionality in *Orcinus* (killer whale). Zoologica 51:71-76.

Schlundt, C. E., J. J. Finneran, D. A. Carder, and S. H. Ridgway. 2000. Temporary shift in masked hearing thresholds of bottlenose dolphins and white whales after exposure to intense tones. Journal of the Acoustical Society of America 107:3496-3508.

Schoonmaker, P. K., T. Gresh, J. Lichatowich, and H. D. Radtke. 2003. Past and present salmon abundance: bioregional estimates for key life history stages. Pages 33-40 *in* J. G. Stockner, editor. Nutrients in salmonid ecosystems: sustaining production and biodiversity. American Fisheries Society, Symposium 34, Bethesda, Maryland.

Schwacke et al. 2002. Need citation.

Secchi, E. R. and T. Vaske, Jr. 1998. Killer whale (*Orcinus orca*) sightings and depredation on tuna and swordfish longline catches in southern Brazil. Aquatic Mammals 24:117-122.

Sergeant, D. E. 1969. Feeding rates of cetacean. Fiskeridirektoratets Skrifter Serie Havundersøkelser 15:246-258.

Sergeant, D. E. and H. D. Fisher. 1957. The smaller Cetacea of eastern Canadian waters. Journal of the Fisheries Research Board of Canada 14:83-115.

Shaw 1998. Need citation.

Shelden, K. E. W., D. J. Rugh, J. L. Laake, J. M. Waite, P. J. Gearin, and T. R. Wahl. 2000. Winter observations of cetaceans off the northern Washington coast. Northwestern Naturalist 81:54-59.

Shelden, K. E. W., D. J. Rugh, B. A. Mahoney, and M. E. Dahlheim. 2003. Killer whale predation on belugas in Cook Inlet, Alaska: implications for a depleted population. Marine Mammal Science 19:529-544.

Shepherd, G. S. 1932. Killer whale in slough in Portland, Oregon. Journal of Mammalogy 13:171-172.

Sigurjónsson, J. and S. Leatherwood. 1988. The Icelandic live-capture fishery for killer whales, 1976-1988. Rit Fiskideildar 11:307-316.

Sih, A., A. M. Bell, and J. L. Kerby. 2004. Two stressors are far deadly than one. Trends in Ecology and Evolution 19:274-276.

Similä, T. and F. Ugarte. 1993. Surface and underwater observations of cooperatively feeding killer whales in northern Norway. Canadian Journal of Zoology 71:1494-1499.

Similä, T., J. C. Holst, and I. Christensen. 1996. Occurrence and diet of killer whales in northern Norway: seasonal patterns relative to the distribution and abundance of Norwegian spring-spawning herring. Canadian Journal of Fisheries and Aquatic Sciences 53:769-779.

Simms, W., S. Jeffries, M. Ikonomou, and P. S. Ross. 2000. Contaminant-related disruption of vitamin A dynamics in free-ranging harbor seal (*Phoca vitulina*) pups from British Columbia, Canada and Washington State, USA. Environmental Toxicology and Chemistry 19:2844-2849.

Simon Fraser University. 1998. Speaking for the salmon: workshop highlights. <http://www.sfu.ca/cstudies/science/salmon/thompson.pdf>.

Simpson, J. C. and M. D. Gardner. 1972. Comparative microscopic anatomy of selected marine mammals. Pages 298-418 *in* S. H. Ridgway, editor. Mammals of the sea: biology and medicine. Thomas, Springfield, Illinois.

Skaare, J. U., H. J. Larsen, E. Lie, A. Bernhoft, A. E. Derocher, R. Norstrom, E. Ropstad, N. F. Lunn, and O. Wiig. 2002. Ecological risk assessment of persistent organic pollutants in the arctic. Toxicology 181-182:193-197.

Slaney, T. L., K. D. Hyatt, T. G. Northcote, and R. J. Fielden. 1996. Status of anadromous salmon and trout in British Columbia and Yukon. Fisheries 21(10):20-35.

Slijper, E. J. 1936. Die cetaceen: vergleichend-anatomisch und systematisch. Reprinted in 1973, A. Asher and Company, Amsterdam, Netherlands.

Small, M. P., A. E. Pichahchy, J. F. Von Bargen, and S. F. Young. 2004. Have native coho salmon (*Oncorhynchus kisutch*) persisted in the Nooksack and Samish rivers despite continuous hatchery production throughout the past century? Conservation Genetics 5:367-379.

Small, R. J. and D. P. DeMaster. 1995. Survival of five species of captive marine mammals. Marine Mammal Science 11:209-226.

Smith, T. G., D. B. Siniff, R. Reichle, and S. Stone. 1981. Coordinated behavior of killer whales, *Orcinus orca*, hunting a crabeater seal, *Lobodon carcinophagus*. Canadian Journal of Zoology 59:1185-1189.

Sniezek, J. H., D. W. Coats, and E. B. Small. 1995. *Kyaroikeus cetarius* n. g., n. sp., a parasitic ciliate from the respiratory tract of odonticete cetacea. Journal of Eukaryotic Microbiology 42:260-268.

Spalding, D. A. E. 1998. Whales of the west coast. Harbour Publishing, Madeira Park, British Columbia.

Springer, A. M., J. A. Estes, G. B. van Vliet, T. M. Williams, D. F. Doak, E. M. Danner, K. A. Forney, and B. Pfister. Sequential megafaunal collapse in the North Pacific: an ongoing legacy of industrial whaling? Proceedings of the National Academy of Science 100:12223-12228.

Stacey, P. J. and R. W. Baird. 1997. Birth of a resident killer whale off Victoria, British Columbia, Canada. Marine Mammal Science 13:504-508.

Stasko, A. B., R. M. Horrall, and A. D. Hasler. 1976. Coastal movements of adult Fraser River sockeye salmon (*Oncorhynchus nerka*) observed by ultrasonic tracking. Transactions of the American Fisheries Society 105:64-71.

Stevens, T. A., D. A. Duffield, E. D. Asper, K. G. Hewlett, A. Bolz, L. J. Gage, and G. D. Bossart. 1989. Preliminary findings of restriction fragment differences in mitochondrial DNA among killer whales (*Orcinus orca*). Canadian Journal of Zoology 67:2592-2595.

Stout, H. A., R. G. Gustafson, W. H. Lenarz, B. B. McCain, D. M. VanDoornik, T. L. Builder, and R. D. Methot. 2001. Status review of Pacific herring (*Clupea pallasi*) in Puget Sound, Washington. NOAA Technical Memorandum NMFS-NWFSC-45, U.S. Department of Commerce, Seattle, Washington.

Strager, H. 1995. Pod-specific call repertoires and compound calls of killer whales, *Orcinus orca* Linnaeus, 1758, in the waters of northern Norway. Canadian Journal of Zoology 73:1037-1047.

Sugarman, P. 1984. Field guide to the orca whales of greater Puget Sound and southern British Columbia. The Whale Museum, Friday Harbor, Washington.

Sweeting, R. M., R. J. Beamish, D. J. Noakes, and C. M. Neville. 2003. Replacement of wild coho salmon by hatchery-reared coho salmon in the Strait of Georgia over the past three decades. North American Journal of Fisheries Management 23:492-502.

Szymanski, M. D., D. E. Bain, K. Kiehl, S. Pennington, S. Wong, and K. R. Henry. 1999. Killer whale (*Orcinus orca*) hearing: auditory brainstem response and behavioral audiograms. Journal of the Acoustical Society of America 106:1134-1141.

Taddei et al. 2001. Need citation.

Tanabe, S. 1988. PCB problems in the future: foresight from current knowledge. Environmental Pollution 50:5-28.

Tanabe, S., H. Iwata, and R. Tatsukawa. 1994. Global contamination by persistent organochlorines and their ecotoxicological impact on marine mammals. Science of the Total Environment 154:163-177.

Tanabe, S., B. G. Loganathan, A. Subramanian, and R. Tatsukawa. 1987. Organochlorine residues in short-finned pilot whale: possible use as tracers of biological parameters. Marine Pollution Bulletin 18:561-563.

Tarpy, C. 1979. Killer whale attack! National Geographic 155:542-545.

Taylor, M. 2004. Southern resident orcas: population change, habitat degradation and habitat protection. Report number SC/56/E32, International Whaling Commission, Cambridge, United Kingdom.

Taylor, M. and B. Plater. 2001. Population viability analysis for the southern resident population of the killer whale (*Orcinus orca*). Center for Biological Diversity, Tucson, Arizona.

Taylor, R. F. and R. K. Farrell. 1973. Light and electron microscopy of peripheral blood neutrophils in a killer whale affected with Chediak-Higashi syndrome. Federation Proceedings (Federation of American Societies for Experimental Biology) 32:8222.

Taylor, R. J. F. 1957. An unusual record of three species of whale being restricted to pools in Antarctic sea-ice. Proceedings of the Zoological Society of London 129:325-331.

Thomas, J. A., S. Leatherwood, W. E. Evans, and J. R. Jehl, Jr. 1981. Ross Sea killer whale distribution, behavior, color pattern, and vocalizations. Antarctic Journal of the United States 16:157-158.

Thomsen, F., D. Franck, and J. K. B. Ford. 2001. Characteristics of whistles from the acoustic repertoire of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia. Journal of the Acoustical Society of America 109:1240-1246.

Thomsen, F., D. Franck, and J. K. B. Ford. 2002. On the communicative significance of whistles in wild killer whales (*Orcinus orca*). Naturwissenschaften 89:404-407.

Tilbury, K. L., N. G. Adams, C. A. Krone, J. P. Meador, G. Early, and U. Varanasi. 1999. Organochlorines in stranded pilot whales (*Globicephala melaena*) from the coast of Massachusetts. Archives of Environmental Contamination and Toxicology 37:125-134.

Tilt, W. C. 1986. Whalewatching in California: survey of knowledge and attitudes. Yale School of Forestry and Environmental Studies, Yale University, New Haven, Connecticut.

Tomich, P. Q. 1986. Mammals in Hawaii. Bishop Museum Press, Honolulu, Hawaii.

Tomilin, A. G. 1957. Mammals of the U.S.S.R. and adjacent countries. Vol. IX. Cetacea. Moscow, Soviet Union (English translation, 1967, Israel Program for Scientific Translations, Jerusalem, Israel).

Transboundary Georgia Basin-Puget Sound Environmental Indicators Working Group. 2002. Georgia Basin-Puget Sound ecosystem indicators report. <http://wlapwww.gov.bc.ca/cppl/gbpsei/documents/gbpsei.pdf>.

Turner, W. 1872. On the gravid uterus and on the arrangement of the foetal membranes in the Cetacea. Transactions of the Royal Society of Edinburgh 26:467-504.

Tyack, P. L. and C. W. Clark. 1998. Quick-look: playback of low-frequency sound to gray whales migrating past the central California coast – January 1998. Unpublished report.

U.S. Department of Commerce and Secretary of the Navy. 2001. Joint interim report: Bahamas marine mammal stranding event of 15-16 March 2000. <http://www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf#search='Joint%20interim%20report:%20Bahamas%20marine%20mammal%20stranding%20event%20of%201516%20March%202000'>

U.S. Environmental Protection Agency. 2003. National Priorities List sites in Washington. <http://www.epa.gov/superfund/sites/npl/wa.htm>.

U.S. Navy, Pacific Fleet. 2004. Report on the results of the inquiry into allegations of marine mammal impacts surrounding the use of active sonar by *USS Shoup* (DDG 86) in the Haro Strait on or about 5 May 2003.

Valsecchi, E., W. Amos, J. A. Raga, M. Podestà, and W. Sherwin. 2004. The effects of inbreeding on mortality during a morbillivirus outbreak in the Mediterranean striped dolphin (*Stenella coeruleoalba*). Animal Conservation 7:139-146.

Van Bressem, M.-F., K. Van Waerebeek, and J. A. Raga. 1999. A review of virus infections of cetaceans and the potential impact of morbilliviruses, poxviruses and papillomaviruses on host population dynamics. Diseases of Aquatic Organisms 38:53-65.

Van Bressem, M.-F., K. Van Waerebeek, P. D. Jepson, J. A. Raga, P. J. Duignan, O. Nielsen, A. P. Di Beneditto, S. Siciliano, R. Ramos, W. Kant, V. Peddemors, R. Kinoshita, P. S. Ross, A. Lopez-Fernandez, K. Evans, E. Crespo, and T. Barrett. 2001. An insight into the epidemiology of dolphin morbillivirus worldwide. Veterinary Microbiology 81:287-304.

Van de Vijver, K. I., P. T. Hoff, K. Das, W. Van Dongen, E. L. Esmans, T. Jauniaux, J.-M. Bouquegneau, R. Blust, and W. de Coen. 2003 Perfluorinated chemicals infiltrate ocean waters: link between exposure levels and stable isotope ratios in marine mammals. Environmental Science and Technology 37:5545-5550.

van Ginneken, A. M., D. K. Ellifrit, and R. W. Baird. 1998. Orca survey field guide to transients of the Haro Strait area. Center for Whale Research, Friday Harbor, Washington.

van Ginneken, A., D. Ellifrit, and K. C. Balcomb, III. 2000. Official orca survey field guide. Center for Whale Research, Friday Harbor, Washington.

van Ginneken, A. M, D. K. Ellifrit, and K. C. Balcomb III. 2005. Official orca survey photo-identification guide to orca whales of the southern resident community. Center for Whale Research, Friday Harbor, Washington.

Vangstein, E. 1956. War against killer whales in Iceland. Norsk Hvalfangst-Tidende 45(10):570-573.

Visser, I. N. 1998. Prolific body scars and collapsing dorsal fins on killer whales (*Orcinus orca*) in New Zealand waters. Aquatic Mammals 24:71-78.

Visser, I. N. 1999a. Antarctic orca in New Zealand waters? New Zealand Journal of Marine and Freshwater Research. 33:515-520.

Visser, I. N. 1999b. Benthic foraging on stingrays by killer whales (*Orcinus orca*) in New Zealand waters. Marine Mammal Science 15:222-227.

Visser, I. N. 1999c. Propeller scars on and known home range of two orca (*Orcinus orca*) in New Zealand waters. New Zealand Journal of Marine and Freshwater Research. 33:635-642.

Visser, I. N. 2000a. Killer whale (*Orcinus orca*) interactions with longline fisheries in New Zealand waters. Aquatic Mammals 26:241-252.

Visser, I. N. 2000b. Orca (*Orcinus orca*) in New Zealand waters. Ph.D. thesis, University of Auckland, Auckland, New Zealand.

Visser, I. N. and F. J. Bonoccorso. 2003. New observations and a review of killer whale (*Orcinus orca*) sightings in Papua New Guinea. Aquatic Mammals 29:150-172.

Visser, I. N. and D. Fertl. 2000. Stranding, resighting, and boat strike of a killer whale (*Orcinus orca*) off New Zealand. Aquatic Mammals 26:232-240.

Visser, I. N. and P. Mäkeläinen. 2000. Variation in eye-patch shape of killer whales (*Orcinus orca*) in New Zealand waters. Marine Mammal Science 16:459-469.

Volpe, J. P., E. B. Taylor, D. W. Rimmer, and B. W. Glickman. 2000. Evidence of natural reproduction of aquaculture-escaped Atlantic salmon in a coastal British Columbia river. Conservation Biology 14:899-903.

Wade, P. R. and T. Gerrodette. 1993. Estimates of cetacean abundance and distribution in the eastern tropical Pacific. Report of the International Whaling Commission 43:477-493.

Waite, J. M. 1988. Alloparental care in killer whales (*Orcinus orca*). M.S. thesis, University of California, Santa Cruz, California.

Waite, J. M., N. A. Friday, and S. E. Moore. 2002. Killer whale (*Orcinus orca*) distribution and abundance in the central and southeastern Bering Sea, July 1999 and June 2000. Marine Mammal Science 18:779-786.

Waknitz, F. W., T. J. Tynan, C. E. Nash, R. N. Iwamoto, and L. G. Rutter. 2002. Review of potential impacts of Atlantic salmon culture on Puget Sound chinook salmon and Hood Canal summer-run chum salmon evolutionarily significant units. NOAA Technical Memorandum NMFS-NWFSC-53, U.S. Department of Commerce, Seattle, Washington.

Walker, L. A., L. Cornell, K. D. Dahl, N. M. Czekala, C. M. Dargen, B. Joseph, A. J. W. Hsueh, and B. L. Lasley. 1988. Urinary concentrations of ovarian steroid hormone metabolites and bioactive follicle-stimulating hormone in killer whales (*Orcinus orca*) during ovarian cycles and pregnancy. Biology of Reproduction 39:1013-1020.

Walsh, M. T., R. Y. Ewing, D. K. Odell, and G. D. Bossart. 2001. Mass strandings of cetaceans. Pages 83-96 *in* L. A. Dierauf and F. M. D. Gulland, editors. CRC handbook of marine mammal medicine. 2nd edition. CRC Press, Boca Raton, Florida.

Walters, E. L., R. W. Baird, and T. J. Guenther. 1992. New killer whale “pod” discovered near Victoria. Victoria Naturalist 49(3):7-8.

Wang, P. 1985. Distribution of cetaceans in Chinese waters. Administrative Report LJ-85-24, Southwest Fisheries Center, National Marine Fisheries Service.

Waples, R. and P. Clapham. 2004. Appendix 6. Report of the working group on killer whales as a case study. Pages 62-73 *in* R. R. Reeves, W. F. Perrin, B. L. Taylor, C. S. Baker, and S. L. Mesnick, editors. 2004. Report of the workshop on shortcomings of cetacean taxonomy in relation to needs of conservation and management, April 28-May 2, 2004, La Jolla, California. NOAA Technical Memorandum NMFS-SWFSC-363, U.S. Department of Commerce, La Jolla, California.

Wardle, W. J., T. A. Haney, and G. A. J. Worthy. 2000. New host record for the whale louse *Isocyamus delphinii* (Amphipoda, Cyamidae). Crustaceana 73:639-641.

Washington Department of Ecology. 2004. Vessel entries and transits for Washington waters, VEAT 2003. WDOE Publication 04-08-002, Washington Department of Ecology, Olympia, Washington.

WDF et al. (Washington Department of Fisheries, Washington Department of Wildlife, and Western Washington Indian Treaty Tribes). 1993. 1992 Washington State salmon and steelhead stock inventory (SASSI). Olympia, Washington.

WDFW (Washington Department of Fish and Wildlife). 2002. 1999-01 Biennial Report. Washington Department of Fish and Wildlife, Olympia, Washington.

WDFW (Washington Department of Fish and Wildlife). 2003. Atlantic salmon. <http://www.wdfw.wa.gov/fish/atlantic/comcatch.htm>.

WDFW (Washington Department of Fish and Wildlife). 2004. Chum salmon. <http://www.wdfw.wa.gov/fish/chum/>.

WDFW and ODFW (Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife). 2002. Status report: Columbia River fish runs and fisheries, 1938-2000. Olympia, Washington and Portland, Oregon.

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-24, Department of Commerce, Seattle, Washington.

Wertheimer, A. C. 1997. Status of Alaska salmon. Pages 179-197 *in* D. J. Stouder, P. A. Bisson, and R. J. Naiman, editors. Pacific salmon & their ecosystems: status and future options. Chapman & Hall, New York, New York.

West, J., S. O'Neill, G. Lippert, and S. Quinnell. 2001a. Toxic contaminants in marine and anadromous fishes from Puget Sound, Washington. Washington Department of Fish and Wildlife, Olympia, Washington.

West, J., S. O'Neill, D. Lomax, and L. Johnson. 2001b. Implications for reproductive health in rockfish (*Sebastes* spp.) from Puget Sound exposed to polychlorinated biphenyls. *In* T. Droscher, editor. Proceedings of the 2001 Puget Sound Research Conference. Puget Sound Action Team. Olympia, Washington.

Whale and Dolphin Conservation Society. 2002. *Orcinus orca* a species complex. Whale and Dolphin Conservation Society, Chippenham, Wiltshire, United Kingdom.

Whale and Dolphin Conservation Society. 2003. Young orca killed in capture attempt. <http://www.wdcs.org>.

Whale Museum, The. 2003. Annual monthly arrivals & departures from the Salish Sea. <http://www.whalemuseum.org/education/library/whalewatch/arrivals.html>.

Whale Watch Operators Association Northwest. 2003. Best practices guidelines - 2003. <http://www.nwwhalewatchers.org/guidelines.html>.

White, D., N. Cameron, P. Spong, and J. Bradford. 1971. Visual acuity of the killer whale (*Orcinus orca*). Experimental Neurology 32:230-236.

Whitehead, H. 1998. Cultural selection and genetic diversity in matrilineal whales. Science 282:1708-1711.

Whitehead, H., L. Rendell, R. W. Osborne, and B. Würsig. 2004. Culture and conservation of non-humans with reference to whales and dolphins: review and new directions. Biological Conservation 120:427-437.

Wiese, F. K. and G. J. Robertson. 2004. Assessing seabird mortality from chronic oil discharges at sea. Journal of Wildlife Management 68:627-638.

Wiles, G. J. 2004. Washington State status report for the killer whale. Washington Department Fish and Wildlife, Olympia, Washington.

Williams, R., D. E. Bain, J. K. B. Ford, and A. W. Trites. 2002b. Behavioural responses of male killer whales to a 'leapfrogging' vessel. Journal of Cetacean Research and Management 4:305-310.

Williams, R., A. Trites, and D. Bain. 2001. Are killer whales habituating to boat traffic? Report number SC/53/WW3, International Whaling Commission, Cambridge, United Kingdom.

Williams, R., A. W. Trites, and D. E. Bain. 2002a. Behavioural responses of killer whales (*Orcinus orca*) to whale-watching boats: opportunistic observations and experimental approaches. Journal of Zoology (London) 256:255-270.

Williams, R. N., P. A. Bisson, D. L. Bottom, L. D. Calvin, C. C. Coutant, M. W. Erho, Jr., C. A. Frissell, J. A. Lichatowich, W. J. Liss, W. E. McConnaha, P. R. Mundy, J. A. Stanford, and R. R. Whitney. 1999. Scientific issues in the restoration of salmonid fishes in the Columbia River. Fisheries 24(3):10-19.

Wydoski, R. S. and R. R. Whitney. 2003. Inland fishes of Washington. 2nd edition. University of Washington Press, Seattle, Washington.

Yamamoto, J. T., R. M. Donohoe, D. M. Fry, M. S. Golub, and J. M. Donald. 1996. Environmental estrogens: implications for reproduction in wildlife. Pages 31-51 *in* A. Fairbrother, L. N. Locke, and G. L. Hoff, editors. Noninfectious diseases of wildlife. Iowa State University, Ames, Iowa.

Yano, K. and M. E. Dahlheim. 1995a. Behavior of killer whales (*Orcinus orca*) during longline fishery interactions in the southeastern Bering Sea and adjacent waters. Fisheries Science 61:584-589.

Yano, K. and M. E. Dahlheim. 1995b. Killer whale (*Orcinus orca*) depredation on longline catches of bottomfish in the southeastern Bering Sea and adjacent waters. Fishery Bulletin 93:355-372.

Ylitalo, G. M., C. O. Matkin, J. Buzitis, M. M. Krahn, L. L. Jones, T. Rowles, and J. E. Stein. 2001. Influence of life-history parameters on organochlorine concentrations in free-ranging killer whales (*Orcinus orca*) from Prince William Sound, AK. Science of the Total Environment 281:183-203.

Yonezawa, M., H. Nakamine, T. Tanaka, and T. Miyaji. 1989. Hodgkin's disease in a killer whale (*Orcinus orca*). Journal of Comparative Pathology 100:203-207.

Yoshiyama, R. M., F. W. Fisher, and P. B. Moyle. 1998. Historical abundance and decline of chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.

Yoshiyama, R. M., E. R. Gerstung, F. W. Fisher, and P. B. Moyle. 2000. Chinook salmon in the California Central Valley: as assessment. Fisheries 25(2):6-20.

Young, N. M., S. Iudicello, K. Evans, and D. Baur. 1993. The incidental capture of marine mammals in U.S. fisheries: problems and solutions. Center for Marine Conservation, Washington, D.C.

Yurk, H., L. Barrett-Lennard, J. K. B. Ford, and C. O. Matkin. 2002. Cultural transmission within maternal lineages: vocal clans in resident killer whales in southern Alaska. Animal Behaviour 63:1103-1119.

Zenkovich, B. A. 1938. On the grampus or killer whale (*Orcinus orca* Lin.). Piroda 4:109-112. (English translation by L. G. Robbins, National Marine Mammal Laboratory, Seattle, Washington).

Appendix A. The current "Be Whale Wise" guidelines recommended for vessels, kayaks, and other craft watching killer whales in Washington and British Columbia by the Soundwatch Boater Education Program and Marine Mammal Monitoring Project (M3).

Whale Watching

1. Be cautious and courteous: approach areas of known or suspected marine mammal activity with extreme caution. Look in all directions before planning your approach or departure.
2. Slow down: reduce speed to less than 7 knots when within 400 meters/yards of the nearest whale. Avoid abrupt course changes.
3. Avoid approaching closer than 100 meters/yards from any whale.
4. If your vessel is unexpectedly within 100 meters/yards, stop immediately and allow the whales to pass.
5. Avoid approaching whales from the front or from behind. Always approach and depart whales from the side, moving in a direction parallel to the direction of the whales.
6. Keep clear of the whales' path. Avoid positioning your vessel within the 400 meter/yard area in the path of the whales.
7. Stay on the offshore side of the whales when they are traveling close to shore. Remain at least 200 meters/yards offshore at all times.
8. Limit your viewing time to a recommended maximum of 30 minutes. This will minimize the cumulative impact of many vessels and give consideration to other viewers.
9. Do not swim with or feed whales.

Porpoises and Dolphins

1. Observe all guidelines for watching whales.
2. Do not drive through groups of for the purpose of bow-riding.
3. Should dolphins or porpoises choose to ride the bow wave of your vessel, reduce speed gradually and avoid sudden course changes.

Seals, Sea Lions and Birds on Land

1. Avoid approaching closer than 100 meters/yards to any marine mammals or birds.
2. Slow down and reduce your wake/wash and noise levels.
3. Pay attention and back away at the first sign of disturbance or agitation.
4. Be cautious and quiet when around haul-outs and bird colonies, especially during breeding, nesting and pupping seasons (generally May to September).
5. Do not swim with or feed any marine mammals or birds.

Viewing Wildlife within Marine Protected Areas, Wildlife Refuges, Ecological Reserves and Parks

1. Check your nautical charts for the location of various protected areas.
2. Abide by posted restrictions or contact a local authority for further information.

To Report a Marine Mammal Disturbance or Harassment:

Canada: Fisheries and Oceans Canada: 1-800-465-4336
U.S.: National Marine Fisheries Service, Office for Law Enforcement: 1-800-853-1964

To Report Marine Mammal Sightings:

BC Cetacean Sightings Network: www.wildwhales.org or 1-604-659-3429
The Whale Museum Hotline (WA state): 1-800-562-8832 or hotline@whalemuseum.org
Orca Network: info@orcanetwork.org

Appendix B. List of major sewage treatment plants and pulp and paper mills in the Puget Sound and Georgia Basin region[a].

Sewage treatment plants

Washington

- Bellingham STP
- Anacortes WWTP
- Mt. Vernon STP
- Everett STP
- Lynnwood STP
- Edmonds STP
- Metro Alki Point, Seattle
- Metro West Point, Seattle
- Salmon Creek WWTP, Burien
- Metro Renton, Renton
- Miller Creek WWTP, Normandy Park
- Midway Sewer District, Des Moines
- Redondo STP, Des Moines
- Lakota STP, Federal Way
- Tacoma Central No. 1
- Tacoma North No. 3
- Chambers Creek, University Place
- Puyallup STP
- Sumner STP
- Enumclaw STP
- LOTT, Olympia area
- Port Angeles STP
- Kitsap County Central Kitsap, Poulsbo
- Bremerton STP
- Shelton STP

British Columbia

- Campbell River
- Comox Valley Regional
- Powell River
- Westview
- Squamish
- Lion’s Gate, Vancouver
- Iona Island, Vancouver
- Lulu Island, Vancouver
- Annacis Island, Vancouver
- Chilliwick
- Northwest Langley
- Nanaimo
- French Creek, Nanaimo
- Ladysmith
- Salt Spring Island
- Sydney
- Clover Point, Victoria
- Macaulay Point, Victoria

Pulp and paper mills

Washington

- Georgia Pacific, Bellingham
- Daishowa America, Port Angeles
- Rayonier[b], Port Angeles
- Port Townsend Paper, Port Townsend
- Kimberley-Clark, Everett
- Simpson Tacoma Kraft, Tacoma
- Sonoco, Sumner
- Stone Consolidated (Abitibi)[a], Steilacoom

British Columbia

- Norske Skog Canada, Elk Falls
- Pacifica Papers, Port Alberni
- Pope & Talbot, Harmac
- Norske Skog Canada, Crofton
- Pacifica Papers, Powell River
- Western Pulp Limited Partnership, Squamish
- Howe Sound Pulp & Paper, Port Mellon
- Norampac Paper, New Westminster
- Scott Paper, New Westminster

---

[a] Adapted from Grant and Ross (2002), with additional information from the Washington Department of Ecology. Many of these sites discharge their effluent directly into marine waters and may have once been significant polluters.

[b] Now closed.

Appendix C. Superfund sites located in the Puget Sound region, with a listing of primary contaminants (U.S. Environmental Protection Agency 2003).

Site name	Location	Contaminated media	Major contaminants
Northwest Transformer, Mission Pole[a]	Everson, Whatcom Co.	Soils, sludges	PCBs, others
Northwest Transformer, S. Harkness St. [a]	Everson, Whatcom Co.	Soils, sludges	PCBs, heavy metals
Oeser Company	Bellingham, Whatcom Co.	Soils, sludges	Others
Whidbey Island Naval Air Station, Ault Field	Whidbey Island, Island Co.	Soils, marine and freshwater sediments, groundwater	PCBs, pesticides, dioxins, heavy metals, others
Whidbey Island Naval Air Station, Seaplane Base[a]	Whidbey Island, Island Co.	Soils, sludges, groundwater, surface water	Pesticides, heavy metals, others
Tulalip Landfill	Marysville, Snohomish Co.	Surface water, soils, marine and freshwater sediments, groundwater	PCBs, DDT, heavy metals, others
Harbor Island	Seattle, King Co.	Soils, marine and freshwater sediments, sludges, groundwater	PCBs, heavy metals, petroleum products, others
Lower Duwamish Waterway	Seattle, King Co.	Freshwater sediments, surface water	PCBs, others
Pacific Sound Resources	Seattle, King Co.	Marine and freshwater sediments, groundwater	PCBs, heavy metals, others
Pacific Car and Foundry (PACCAR)	Renton, King Co.	Soils	PCBs, heavy metals, petroleum products, others
Midway Landfill	Kent, King Co.	Groundwater	Heavy metals, others
Seattle Municipal Landfill	Kent, King Co.	Groundwater	Heavy metals, others
Western Processing Company	Kent, King Co.	Soils, freshwater sediments, groundwater	PCBs, dioxins, heavy metals, others
Queen City Farms	Maple Valley, King Co.	Soils, sludges, groundwater, surface water	PCBs, heavy metals, others
Port Hadlock Detachment, U.S. Navy	Indian Island, Jefferson Co.	Marine sediment, shellfish, soils, groundwater	PCBs, pesticides, heavy metals, others
Naval Undersea Warfare Center	Keyport, Kitsap Co.	Soils, marine sediments, shellfish, groundwater	PCBs, heavy metals, petroleum products, others
Bangor Naval Submarine Base	Silverdale, Kitsap Co.	Soils, sludges, surface water, groundwater	Others
Bangor Ordnance Disposal, U.S. Navy	Silverdale, Kitsap Co.	Soils, sludges, surface water, groundwater	Others

Appendix C. Superfund sites in the Puget Sound region (cont'd).

Site name	Location	Contaminated media	Major contaminants
Wyckoff Company/Eagle Harbor	Bainbridge Island, Kitsap Co.	Soils, marine sediments, groundwater	Dioxins, furans, heavy metals, others
Jackson Park Housing Complex, U.S. Navy	Bremerton, Kitsap Co.	Soils, sludges, surface water	Heavy metals, others
Puget Sound Naval Shipyard Complex	Bremerton, Kitsap Co.	Soils, sludges, marine sediments, groundwater	PCBs, heavy metals, petroleum products, others
Old Navy Dump/Manchester Lab	Manchester, Kitsap Co.	Soils, sludges, marine sediments, surface water, shellfish	PCBs, heavy metals, petroleum products, others
Commencement Bay Nearshore/ Tideflats	Tacoma, Pierce Co.	Surface water, soils, marine sediments, groundwater	PCBs, heavy metals, others
Commencement Bay South Tacoma Channel	Tacoma, Pierce Co.	Surface water, soils, marine sediments, groundwater	PCBs, heavy metals, petroleum products, others
American Lake Gardens, McChord AFB	Tacoma, Pierce Co.	Groundwater	Others
McChord AFB (Wash Rack/Treat)[a]	Tacoma, Pierce Co.	Groundwater	Petroleum products, others
Lakewood Site	Lakewood, Pierce Co.	Soils, sludges, groundwater	Others
Hidden Valley Landfill (Thun Field)	Puyallup, Pierce Co.	Groundwater	Heavy metals, others
Fort Lewis (Landfill No. 5)[a]	Fort Lewis, Pierce Co.	Groundwater	Heavy metals, others
Fort Lewis Logistics Center	Fort Lewis, Pierce Co.	Groundwater	Heavy metals, others
Palermo Well Field	Tumwater, Thurston Co.	Soils, surface water, groundwater	Others

[a] Cleanup activities considered complete.